A BIOECONOMIC MODEL FOR IMPROVING THE MANAGEMENT OF NATURAL RESOURCES: AN APPLICATION TO THE CHAM SCALLOP (*Patinopecten yessoensis*) AQUACULTURE IN KOREA

By

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He who observes the wind will not sow, and he who regards the clouds will not reap.
(Ecclesiastes 11:4)

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This study specified and estimated a bioeconomic model of the cham scallop (*Patinopecten yessoensis*) industry in Korea that can be used to improve management decisions (both public and private). The methodology is unique in the number of dimensions considered, namely, multiple geographic regions and culture method. The model required estimation of (1) a price-weight relationship to account for the benefit of additional growth from delaying harvest, (2) fixed and variable costs of each culture method (lantern net and ear-suspended), and (3) growth functions that used environmental variables (water temperature, salinity, and dissolved oxygen) to explain changes to shell length.

To account for stochastic growth, simulations were conducted using probabilities of alternative environmental states (27 total) for each region, style, and month. The

probabilistic growth figures were then combined with mortality estimates and the price equation to estimate expected net revenues. By subtracting the estimated fixed and variable costs, the optimal harvest times and rotations were calculated to maximize the net present value (NPV) of the rotation.

The resulting NPV estimates differed by as much as 26 percent. The highest returns were associated with production using the ear suspended style in Kojin. The optimal (NPV-maximizing) planting period ranged from March to July and the optimal grow-out ranged from 19-24 months depending on the region and culture method. Since these results were derived under specific assumptions regarding prices, demand, costs, growth, mortality rates, etc., evaluation of the results should focus on the type of information this methodology can generate rather than the specific figures. The strength of this approach lies in the ability to systematically evaluate the economic and biological tradeoffs associated with changing production schedules.

Comparing NPV estimates (48 total) revealed potential gains from altering both private and public management. Private managers (farmers) may be able to increase economic returns by delaying harvest in order to market larger, more valuable scallops (e.g., from the 10-12 cm current market size to the optimal size of 11.93-13.04 cm). Resource managers, for example, may be able to increase the value of the industry by adjusting the licensing system from a fixed fee to one that accounts for these economic differences.

CHAPTER 1
INTRODUCTION

An increasing world population and potential for a shortage of animal protein has led in part, to an increase in the exploitation of marine resources and has stimulated interest in aquaculture. The potential for aquaculture in particular is promising given the worldwide success with salmon and shrimp species. For the relatively high valued shellfish species especially those that thrive in shallow coastal waters, aquaculture has the potential to increase local incomes. In addition, the ratio of protein yield to metabolisable energy required to produce fish is at least twice that of chicken or dairy cows (Talpaz and Tsur, 1982).

Under certain conditions, aquaculture production may also possess a comparative advantage over wild harvesting (Shang, 1981). This is because wild populations can be widely dispersed due to natural ecological dynamics or as a result of targeted harvest pressure. Dispersion in turn can affect the per unit harvest costs by increasing search time (opportunity costs of labor, fuel, grocery expenses, etc.). On the other hand, aquaculture may reduce unit costs by regionally concentrating the target species. Aquaculture also allows for better control of product quality and supply that can help to mitigate adverse seasonal fluctuations in price and possibly even increase prices.

In Korea, consumption of fishery products has increased since 1980; per capita consumption for fish reached 43.6 kg in 1997, which represents a 61 percent increase over consumption levels in 1980 (Hong et al., 1999). For comparison, this increase is second only to the other protein group (meat). Consumption of fruit and vegetables has

increased very little while consumption of rice actually declined during the same time period (Table 1-1) Like the fruit and vegetable group, however, annual average consumption of fish declined slightly from a peak in the mid 1990s

Table 1-1 Korean Annual per Capita Consumption (kg) by Food Group

Year	Rice	Fruit and Vegetable	Meat	Fish
1980	132 9	136 8	13 9	27 0
1985	128 0	125 2	16 5	37.2
1990	120 8	161 6	23 6	36.2
1995	110 6	160 6	32 7	45 1
1997	104 6	148 2	35 2	43.6

The domestic supply of seafood in Korea is obtained from coastal and long-distant fishing fleets The coastal fisheries are divided into aquaculture and wild capture operations The long-distant fisheries are comprised of vessels that travel to other parts of the world to fish Production (landings) by both the coastal and long-distant fisheries has declined steadily in recent years (Table 1-2) According to the Korea National Statistical Office (KNSO) total fishery landings declined 15 percent from 1993 through 1998 (six years)

Table 1-2 Fishery Landings (mt) in Korea, 1993-1998

Year	Coastal Fisheries	Long distant Fisheries	Total
1993	1,526 139	1 809 392	3,335 531
1994	1 486,357	1 990,230	3 476 587
1995	1,425,213	1 922,971	3,348 184
1996	1,623 822	1 620 466	3,244 288
1997	1,367 406	1 876,319	3,243 725
1998	1 308,336	1 526 679	2 835 015

Source Korea National Statistical Office (KNSO), 2000

An observation of landings trends and consumption patterns can help to identify the potential demand for additional sources of seafood. A recent study by Hong et al. (1999) found that Korean seafood demand is expected to reach 767,000 mt by 2010 which would be a 51 percent increase over the observed seafood consumption level of 507,000 mt in 1997.

In response to the potential increase in demand and observed reduction in supply, the Ministry of Maritime Affairs and Fisheries (MMAF) in Korea increased its effort to promote aquaculture in the early 1990s. The most significant promotion efforts were concentrated toward research aimed at increasing productivity (i.e., production yields). Consequently, aquaculture production has experienced rapid growth to become one of Korea's most important fishing industries. For example, Korean aquaculture production increased 20 percent (from 0.8 million mt to one million mt) between 1996 and 1997 or just one year (Food and Agriculture Organization, 1999).

The churn scallop (*Patinopecten yessoensis*) species in particular responded especially well to culturing techniques and Korean production gradually increased beginning in 1990. For example, in Kangwon province the volume of churn scallops produced using aquaculture increased 298 times from 6.2 mt to 1,852 mt from 1991 to 1996 (six years) (Table 1-3). During that same time period the production area increased from 85 ha to 5,337 ha (61 times). Given that production volumes increased relatively more than the area used for production, it is not surprising the yields also increased during this period. In particular, production per hectare (mt/ha) increased from 0.073 to 0.347 (a factor of 3.75). The industry decline in 1998 was due to a hurricane that struck Kangwon province.

Table 1-3. Charn Scallop Production Statistics in Kangwon Province, 1991-2000

Year	Landings (mt)	Area (ha)	Yield (mt/ha)
1991	6.2	85.0	0.073
1992	63.0	807.5	0.078
1993	200.0	1,422.1	0.141
1994	605.0	2,160.6	0.280
1995	1,233.0	4,068.6	0.303
1996	1,852.0	5,337.1	0.347
1997	1,333.0	4,215.2	0.316
1998	574.0	4,198.4	0.137
1999	858.5	3,326.1	0.258
2000	1,131.0	4,121.8	0.274

Source: Kangwon Charn Scallop Association (KCSA). 2001

Kangwon is an area around the Northeast Sea in Korea (Figure 1-1). Kangwon's natural environmental conditions are particularly well-suited for charn scallop production due to relatively warm water temperatures, which promote faster growth (Park, 1998). The major producing regions are Cheomanjin and Kojin.

Charn scallop production accounted for just one percent of total Kangwon aquaculture production in 1991. By 1996, however, charn scallop's share of total aquaculture production reached 77.9 percent (Table 1-4). Total aquaculture production in Kangwon province was 2,376 mt in 1996. Aside from charn scallops, sea squirts, sea urchins, and finfish are also cultured in Kangwon. By 1996, however, aquaculture production of sea squirts and sea urchins fell to zero. In the case of sea squirts, culture had reached 1,273 mt in 1992 so the decline is especially notable but has since increased due to high prices. Aside from charn scallops, finfish culture has also increased since 1991.

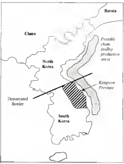

Figure 1-1. Kangwon Province and the Primary Cham Scallop Culture Region in Korea

In terms of value, the cham scallop aquaculture industry reached 10.8 billion won in 1996, which accounted for 64.5 percent of the total value of aquaculture production in Kangwon Province (Table 1-5). In 1996, nearly all of the remaining value of aquaculture production (35.1 percent) was from fish species.

Table 1-4 Landings (mt) of Aquaculture Fisheries in Kangwon, 1991-2000

Year	Fishery					Total	Cham's Share (%)
	Cham scallop	Sea squirt	Sea urchin	Fish	Other		
1991	6.2	491	0.1	120	0.1	617	1.0
1992	63.0	1,273	1.0	213	0.0	1,550	4.1
1993	200.0	98	0.0	274	0.0	571	35.0
1994	605.0	78	0.2	406	0.3	1,090	55.5
1995	1,233.0	100	0.0	359	0.3	1,692	72.9
1996	1,852.0	0	0.0	521	3.3	2,376	77.9
1997	1,333.0	343	0.0	484	0.0	2,160.0	61.7
1998	574.0	15	0.0	878	0.0	1,467.0	39.1
1999	858.5	338	0.0	1,007	10.0	2,213.5	38.8
2000	1,131.0	1,079	0.0	1,127	40.0	3,777.0	33.5

Source: Kangwon Department of Fisheries (KDF) 2001

Table 1-5 Value (million won) of Aquaculture Fisheries in Kangwon, 1991-2000

Year	Fishery					Total	Cham's Share (%)
	Cham scallop	Sea squirt	Sea urchin	Fish	Other		
1991	37	268	5	1,608	2	1,919	1.9
1992	348	566	27	2,556	0	3,497	10.0
1993	955	81	0	3,449	0	4,486	21.3
1994	3,276	61	7	5,617	16	8,977	36.5
1995	7,058	95	0	4,024	38	11,215	62.9
1996	10,838	0	0	5,904	66	16,808	64.5
1997	7,521	243	0	5,214	0	12,987	58.0
1998	3,901	12	0	8,763	0	12,676	30.8
1999	4,830	167	0	10,707	10	15,714	30.7
2000	6,707	530	0	9,619	32	16,888	39.7

Source: Kangwon Department of Fisheries (KDF) 2001

It should be noted that production and value fell following the 1996 hurricane but the industry has since rebounded In addition, the 'other' category is primarily seaweed.

The Management Problem

Fishery resource management in Korea involves two levels of government. (1) the central government known as the Ministry of Maritime Affairs and Fisheries (MMAF) and (2) local governments at the provincial, city and district levels Korean laws concerning resource protection and legislation relating to the Exclusive Economic Zone (EEZ) provides the framework for fisheries management, including aquaculture During the past fifty years fishery resources have been managed by MMAF using traditional input and output controls including mesh size restrictions area closures seasonal quotas, total quotas, and license limitations

For the charn scallop aquaculture industry, the provincial government opens the spat collection season to avoid the spawning season The season currently opens in June since charn scallops spawn from mid-April through May The industry is predominantly a small-boat fishery as scallops live in relatively shallow water (i e between 10 and 30 m) Other regulatory controls include gear restrictions (i.e., maximum boat size is 10 ton) to prevent destruction of the habitat including coastal pollution The government also controls the farm size through limitations on the number of hectares covered by spat collection permits and grow-out licenses In addition, farm ownership is controlled to some extent since permit and licenses holders are only allowed to participate in aquaculture operations, not any other type of fishery or industry (Park et al., 1997)

Charn scallop grow-out operations (farms) can either collect or purchase spat If a farmer collects spat, they are required to have a permit Permits are sold for 10 000 won

and allow the farmer to harvest 10 hectares in a specific region. A license is also required to grow-out charn scallops. The license fee is 12,000 won and allows farmers to grow-out charn scallops on 30 hectares.

Two grow-out styles can be used, namely, lantern nets or ear suspended. Lantern nets stand well in the water due to horizontal partitions that allow the scallops to congregate around the circumference which improves access to feeding and provides protection from predators. The ear-suspended style has more risk of predation than the lantern net style. The ear-suspended style involves attaching the scallops to a line by using a wire or plastic tag passed through a hole drilled in the ear of the shell which can allow predators to directly access the scallop. Therefore, the success of scallop grow-out operations is likely to vary by culture method.

A commercial culturist may choose to operate at all levels of production or decide to specialize. Hence, a choice of level of integration must be made. Similarly, optimal production scheduling is affected by spat size, planting densities, monitoring schedules, etc. Additional decisions are required on marketing strategies such as whether to target seasonal markets, what size scallops to harvest, and where to market (i.e., local or other regions).

The research presented in this dissertation focuses on optimal production strategies for the grow-out phase of producing charn scallops in Korea. Production decisions such as when to begin grow-out (i.e., when to plant the spat), what type of technology to use, where to grow-out, and the duration of grow-out relate to both private and public management. Thus, optimal results pertaining to firm-level (farm) management options can be used to identify the economic effects of the tradeoffs

associated with changing management plans. These tradeoffs have implications for optimal resource management strategies at the government level

Objectives

The specific objectives of this study are as follows

- to describe the Korean cham scallop aquaculture industry
- to specify a bioeconomic model that can determine the optimal timing of spat placement (season opening) and duration of grow-out (harvest date) for each production style and production location given stochastic environmental conditions,
- to empirically estimate the underlying economic and biological functions (e.g., price, cost, and growth) necessary to optimize and simulate maximum discounted economic returns from a single grow-out rotation, and
- to use the empirical bioeconomic results to derive implications for optimal production scheduling and future management of the resource.

Summary and Overview

During the 1990s Korea has experienced a steady decrease in its fishery production. On the other hand the consumption for seafood in Korea is expected to increase 51 percent by 2010 (Hong at al., 1999). A solution for these two contrasting trends is needed. With the continuing rise in the Korean per capita Gross National Product, the demand for high-valued seafood products could be expected to continue. In fact, the Korean government has attempted to increase production of aquacultured seafood through a comprehensive plan that promised investment of 2 766 million won from 1999 to 2011 (MMAF 1999)

Currently, over ten marine species are commercially cultured in Korea. They are divided into three main groups fishes bivalves and seaweed Compared to other bivalves such as oysters and clams, cham scallops are considered a luxury food item since they command a higher price In 1996 77.9 percent of total aquaculture landings in

Kangwon province were accounted for by cham scallops, thus, the cham scallop aquaculture industry is very important to the economy in Kangwon.

The current situation in the cham scallop farming is characterized by potentially avoidable shortcomings. Farming methods and regional characteristics are not adequately considered in the management of the resource. Consequently, the full income potential for an individual cham scallop aquaculture farm and the industry as a whole is not being realized. More specifically, considerations over production decisions that may need to be considered jointly to optimize the use of the resource (such as harvest scheduling, farming methods, and rotation schedules) are largely ignored. Also, there is a question of efficiency in the current aquaculture license fee structure. All the aquaculture farms pay the same amount for spat collection and grow-out licenses, regardless of the culture style and region that may affect production yields, harvest costs, and scallop size. This system fails to consider the potential economic benefits from optimizing farm-level strategies and designing resource management plans that allow the capture of those benefits.

The specific objectives outlined earlier are designed to address these issues. To that end, the objectives of this dissertation are addressed in Chapters 2 through 7. Chapter 2 describes cham scallop aquaculture production in Korea, including the biological issues and phases of production. Chapter 3 describes the methodological approach used and literature relevant to this study. Chapter 4 describes the data that was collected and assembled for use in estimating the components of the bioeconomic model. Chapter 5 then describes the empirical results of the submodels including the price, cost, and growth functions. Chapter 6 describes the optimization and simulation results that are used to identify the net present value maximizing production schedules. Chapter 6 also

addressed how the results can be used to calculate tradeoffs from choosing an alternative strategy and also discussing the use of the results for analyzing optimal multiple rotations. Chapter 7 is the last chapter and it includes a summary of results, implications of the results, suggestions for future research, and important caveats regarding the interpretation of the results. A list of references follows.

CHAPTER 2
CHAM SCALLOP AQUACULTURE IN KOREA

Background

In recent years aquaculture in Korea has received much attention as a new and potentially lucrative industry There are roughly 360 species of scallops worldwide and most of these are found in coastal waters to a depth of 100 m. The majority of scallop species in Korea live in shallow water between 10 and 50 m (Korea National Fisheries Research and Development Institute, KNFRDI 1997) Being rich in glycogen and protein, scallop meat is highly nutritious and has become much sought after Six species of scallop are native to Korea, namely cham (*Patinopecten yessoensis*), Korang (*Chlamys swifti*) bidan (*Chlamys farreri nipponensis*) kukja (*Pecten albicans albicans*), sea (*Amusium japonicum japonicum*) and common (*Chlamys nobilis*) Scallops in Korea have been a late entrant on the shellfish culturing scene but, as demand has increased so has production In addition the aquaculture techniques have become more refined and yields have improved substantially

Kangwon province has always played an important part in the scallop fishery of Korea. Water temperature in Kangwon is excellent for scallop growth but also encourages other organisms that are undesirable to the commercial grow-out industry At the height of summer algae often appear in the digestive system of the scallops. If this meat goes for human consumption it can cause severe gastric problems By the end of September scallops are also vulnerable to worms, which can bore through the shells to

attack the meat (KNFRDI, 1997). Consequently, intra year timing of harvest can significantly affect the quantity and quality of marketable scallops.

In Kangwon, aquaculture licenses and farming sites are controlled by the Kangwon Department of Fisheries (KDF). Sites are controlled for the protection of fishery resources and to limit pollution. As shown in table 2-1, aquaculture licenses of cham scallops account for about 59 percent of the total number of aquaculture licenses issued in Kangwon. In 1996, cham scallop aquaculture sites accounted for about 77 percent of the total area used for aquaculture in the province. Thus, cham scallop aquaculture has developed into an economically important industry in Kangwon province.

Table 2-1. Number of Aquaculture Licenses and Collective Size of the Grow-out Sites (ha) in Kangwon Province in 1996

City or County	Cham scallop	Sea squirt	Sea-urchin	Fin Fish	Other	Total
Licenses						
Kangnung	19	2	0	12	0	33
Schokcho	5	0	0	0	1	6
Shamchuck	11	5	0	3	1	20
Kosung	11	1	2	3	2	19
Yangyang	8	0	0	5	0	13
Total	54	8	2	23	4	91
Hectares						
Kangnung	94.0	15.0	0.0	10.6	0.0	119.6
Schokcho	40.5	0.0	0.0	0.0	3.0	43.5
Shamchuck	47.5	29.0	0.0	0.7	1.0	78.2
Kosung	54.0	3.0	5.0	1.3	11.0	74.3
Yangyang	41.1	0.0	0.0	2.1	0.0	43.1
Total	277.1	47.0	5.0	14.8	15.0	358.7

Source: Kangwon Department of Fisheries (KDF), 1997

Current methods of chain scallop culture in Kangwon are hanging culture and sowing culture. Hanging culture is carried out by suspending scallops in the water from either a line or a raft. There are two types of hanging culture, lantern net and ear hanging, as described earlier. Ear hanging was developed to reduce production costs, although results have also shown higher growth rates. According to a 1997 profit analysis, ear hanging culture was more profitable than lantern nets for chain scallop culture in Kangwon (Park et al., 1997). However, this study used the average reported price (which was constant across all sizes) and the reported production figures. It was not a bioeconomic analysis so the optimal harvest schedule could not be determined.

Sowing culture is a grow-out method that involves scattering 3 to 6 cm spat on the sea bottom and harvesting after two or three years when they are expected to be of marketable size. Since the scallops are not attached to nets, as with hanging culture, they are free to disperse and are more vulnerable to predators. By comparison, the survival rate associated with sowing culture is lower (50 to 80 percent versus 90) and the grow-out period is longer (by approximately six months) than that of hanging culture (Park et al., 1997). In addition, prices are lower since the scallops are likely to contain sand due to their grow-out habitat.

Chain scallops cultured using the sowing method were first harvested in 1994 with a yield of 17 mt. By 1996, production increased to 267 mt. This growth indicates the potential profitability of this grow-out method. It should be noted that this industry provides the spat needed for the hanging culture operations and, due to its relatively low capital investment, it could provide a valuable source of additional income for coastal communities.

Once the scallop shells are 10 cm in length, harvest usually begins. This is because the marketable size of cham scallops in Korea is between 10 and 12 cm (Park et al., 1997). Although many scallops reach the same size at the same time, production and harvest occur continuously in order to maintain constant supplies as inventory costs can be prohibitive.

The successful aquaculture of cham scallops in Korea must address many elements of uncertainty. On the supply side, changes in environmental conditions affect the size and condition of the scallops. On the demand side, fresh scallops are generally preferred to frozen. Since the volume and weight of a cham scallop is relatively high and variable and they can easily spoil, they are not traded in the market place as a homogeneous commodity.

Farmed cham scallops reach the consumers through two main distribution routes. In the first route, farms sell directly to consumers at the harvest site. The main target for this route is the local population and tourists. The second route involves many levels of middlemen between the producer and consumer. Harvested cham scallops are typically sold to wholesalers in the production area who then sell to wholesalers in the consumption area that distribute to retailers.

Biology of Cham Scallop

Hydrographic data from the scallop culture grounds indicates that the coastal attributes of Kangwon province (i.e., the East Sea) explain the abundance and successful aquaculture of cham scallops in this area (Park, 1998). Water temperature varies from 3.4 to 22.9°C at 10 m. For much of the 1990s, however, the water temperature fell within the range for maximum scallop growth, which is 10 to 18°C. Maximum cham scallop

growth rates are also associated with salinity levels of 32.7 to 37.0 percent, dissolved oxygen content from 4.14 to 8.21 ml/l, chemical oxygen demand from 0.23 to 1.18 mg/l and water transparency from 6.2 to 18.0 m of visibility (Park, 1998).

The spawning period of scallops along the coastal area of Kangwon province begins in April and continues until early June, peaking in late April to early May. The gonad somatic index (GSI) reaches its maximum value in late April for scallops cultured using hanging methods (i.e., lantern nets and ear suspended). Scallops raised on the bottom (i.e., sowing culture) exhibited their maximum GSI two weeks later on average. The annual cycle of the scallops is generally divided into five distinct phases: (1) inactive (October), (2) growth (November to February), (3) maturation (March to April), (4) spawning (April to June), and (5) recovery (July to September) (Park, 1998).

The process of culturing clam scallops begins with successful fertilization that produces a microscopic zygote, which develops through stages (i.e., trochophore and veliger) into a larva. The larvae are subject to tidal movements and plankton-eating predators. In general, density of the swimming larvae is higher in the northern region than the central and southern coastal regions. The higher density could be due to the mixing of larvae of two different origins: the upper northern area via the North Korean Cold Current and the coastal waters of northern Kangwon province. The density of swimming larvae was, however, found to be higher at central regions such as Chumunjin and Kojin after 1995.

The distribution range of swimming larvae is 25 km offshore from the coastline in the northern area due to the influence of the North Korea Cold Current. The distribution is narrower, about 12 km from the coastline, in southern areas below the East Sea that are

influenced with the warm Kuroshio Current. The highest densities of swimming larvae were estimated to be at 10 to 25 m which falls within 4 km of the coastline

The daily growth rate of swimming larvae measures 4.4 to 6.0 microns (μm) per day (average 5.3 μm/day) which translates into 38.1 to 47.8 days for growing into attachable spat size from spawning (Park, 1998) Three to four months after fertilization the spat will have dropped to the sea bed to grow into a fully mature scallop Approximately 20 months after fertilization the scallop will be over 10 cm and ready to harvest

Production Process of Cham Scallop Aquaculture

Natural Spat Collection

Spat monitoring is the practice of setting collector bags on a particular site to check for the presence of wild spat Spat monitoring of cham scallop in Kangwon indicates when enough spat are present to warrant collection In general, the spat should be collected when the median value of the density distribution reaches 220 to 240 μm since they are easiest to attach to collector bags at that size (Park, 1998)

Examination into the timing of settlement of the larvae and the density of settled spat on the collector bags indicates that the swimming larvae settle on substrates during the middle of May and late June At this stage the larvae can be up to 300 μm in size and are usually referred to as "spats" at this point (Park, 1998) However the timing of settlement varies from year to year depending on water temperature When the water is relatively cool, the larvae swim for longer periods and have higher settlement rates (Park 1998) Vertical distribution of the larvae in the water column for spat collection ranges from 10 to 20 m in northern areas, 12 to 25 m in central areas, and 15 to 25 m in southern

coastal regions (Park, 1998). Daily growth rate of the juvenile scallops in the collector bags is estimated to be 0.032 to 0.188 mm per day (Park, 1998). The highest daily growth rates are usually observed during June and July.

Nursery Phase

The nursery phase oversees the growth of the spat to the length of 5 cm. The spats are kept on sites that are protected from predators. Growth of the juvenile scallops during the nursery phase varies from approximately 0.02 to 0.38 mm per day and appears to be affected by water temperature (Park, 1998). Growth of the scallops is considered to be faster during March and April and slower during January and February. Daily growth rate of juvenile scallops placed at different water depths indicates that the fastest growth occurs between 10 and 15 m.

Grow-out Phase

The monthly growth rate of scallops as measured by changes in shell height (mm) for grow-out using the hanging culture method generally exhibits two peak growth periods (in spring and fall). Shell growth of the scallops seems to be influenced most by water temperature (Park, 1998). Growth of the scallops is also greatly affected by density in the net: scallops placed in lower densities (i.e., 5 shells/net) exhibited faster growth (i.e., 0.124 mm/day on average) than scallops placed in higher densities (i.e., 18 shells/net), which showed a much slower growth rate (i.e., 0.098 mm/day on average) (Park, 1998). Dead scallops are generally not observed in nets containing fewer than 10 scallops. The survival rate at higher densities is estimated at 94 percent (Park, 1998). Scallops raised using the ear hanging method exhibit more rapid growth in shell height and total weight, than scallops raised using lantern nets. Overall, scallops raised using

either hanging method will take 20 to 28 months to become 10 to 12 cm in shell height and 130 to 200 g in total weight (Park, 1998)

Summary and Overview

In Korea, charn scallops are found primarily near the coast of Kangwon province, which has water conditions (i.e., appropriate temperature dissolved oxygen, and salinity levels) that are suitable for scallop growth The spawning period lasts between April and June and the survival rate of the larvae is very high within four kilometers from the coasts of the Chumunjin and Kojin areas of Kangwon which range from 10 to 25 m

The process of the charn scallop farming is composed of three phases The natural spat collection phase involves gathering larvae from the sea with collector bags After collection, the spat are allowed to grow into juveniles (5 cm) during the nursery phase where they are protected from predators The density of spat placement affects the overall survival rate during this phase The final grow-out phase involves placing the spat into nets and allowing them to reach the traditional market size of 10 to 12 cm

In Kangwon province charn scallop aquaculture accounted for 59 percent of the total number of aquaculture licenses and 77 percent of the total aquaculture area in 1996 Thus, the charn scallop aquaculture industry is very important to the economy of Kangwon. Traditionally the hanging culture method (either lantern nets or ear-suspension) has been used to grow-out charn scallops for harvest at sizes ranging from 10 to 12 cm

For the empirical analysis both types of hanging culture will be modeled There is no available data to include the sowing culture at this time The two primary culture

regions (Chumunjan and Kojin) will also be modeled. The model will be restricted to examining the final grow-out phase and the market of fresh scallops.

CHAPTER 3
THEORETICAL PERSPECTIVE AND METHODOLOGY

If the fishery resource is common property (i.e. owned by all citizens) and is "open access" then anyone can harvest. In this case, an individual fisherman makes harvesting decisions based only on the relative costs of fishing (excluding the opportunity cost of harvest) and the expected value of the catch. Gordon (1954) demonstrated that the level of exploitation determined in the common property (open access) case would yield less fish than its capacity on a sustained basis. In addition, labor and capital would be oversupplied so that their value of marginal productivity in fishing would be below the corresponding opportunity costs (i.e. the value to society of using the labor and capital in the next best alternative). The result is economic overfishing. This concept is relevant to the clam scallop fishery since the spat that is needed for the aquaculture operations is obtained (collected) from the wild.

If the fishery resource is private property, we would expect the profit motive to result in an efficient harvest operation wherein the harvest rate would increase as long as the marginal cost of harvesting was less than the marginal revenue. A fishermen having such property rights would place a significant value on the unharvested stocks as a source of future income. He would include in his determination of opportunity cost (cost of harvesting a fish today) the value of not harvesting and allowing the stock to grow and/or reproduce. Under private ownership, generally, the total costs of harvesting are taken into account in the harvesting decision, including the costs of depleting the productive stock.

The general resource management problem can be described using capital theory as presented by Dorfman (1969). Using the capital-theoretic approach, a fish population can be viewed as a capital stock in that, like "conventional" or man-made capital, it is capable of yielding a consumption flow through time. The fish stock can be combined with other resources (inputs) such as fishing boats, the labor of fishermen, costs, etc. to produce a good that people value. Therefore, the management problem is to select an optimal harvest path through time (Clark and Munro, 1975).

Optimal Harvest Literature

To analyze the optimal harvesting time for farmed fish, Pontryagin (1962) introduced the mathematical theory and maximum theory for optimal decisions. He concluded that the decision to replace or keep the existing stock for another period should be based on a comparison of the returns from replacing (immediate harvest) with the opportunity costs of keeping the stock or asset another period (delaying harvest). This theoretical approach to optimal decision making has since been applied to fisheries management at the private and public level (i.e. for the boat or farm and government regulatory agencies).

In a recent study involving shrimp aquaculture, Tian et al. (2000) developed a computer simulation model to increase production by changing stocking regimes and farm sizes. This research concluded that a weekly stocking and harvesting regime increased profitability more than a biweekly or 8-week stocking and harvesting regime. An earlier study, also involving shrimp, determined an optimal (net present value maximizing) harvesting pattern using a multi-period mathematical programming model that included prices, fishing effort, catch and resource dynamics (Onal et al., 1991). The study found that optimal effort levels were lower than the status quo and that changing

the size composition of the harvest was beneficial to both producers and consumers. As an example of another study that used a bioeconomic modeling approach and another application to shrimp aquaculture, Leung et al. (1993) developed model specifications for different shrimp species based on the nature of the stochastics. In general, bioeconomic models are used to identify opportunities for increasing economic efficiency through, for example selection of the optimal age at which to harvest each cohort, by integrating the relevant biological (i.e., multiple and distinct cohort dynamics) physical and economic production elements.

In order to incorporate the inherent risk involved in aquaculture production (e.g., due to variation in environmental conditions that affect growth and survival) Hohman (1993) used the Markovian transition matrix approach to model probabilistic growth that was combined with economic data to determine the optimal grow-out and replacement scheduling of hard clams. Results suggested that farmers may need to purchase larger seed and plant at higher densities to increase economic returns. The incorporation of a Markovian process to model stochastic growth was also adopted by Rizzo and Spagnolo (1996) to optimize and simulate the optimal management of a sea bass aquaculture farm. The analysis found that alternative harvest and stocking strategies provide distinct contributions to plant utilization and, ultimately, the present value of economic returns.

In a recent study that explicitly examined optimal rotation strategies Martinez et al. (2001) utilized the bioeconomic modeling approach to compare one and two cycle (rotation) strategies for shrimp aquaculture given variability in water temperatures. The study concluded that the two-cycle strategy was more effective

Conceptual Bioeconomic Framework

Biological and economic information is needed in order to optimally manage a scallop aquaculture operation/industry. Figure 3-1 shows the primary causal pathways and model boundaries. At each point in time, scallop growth is determined by its age/size, growth rate, survival rate, and mortality rates which are, in turn, determined by environmental conditions (e.g., water temperature, salinity, dissolved oxygen). At the individual firm level, the stocking rate, culture method, and geographic location of the farm (i.e., region) affects harvest levels. The decision of when to harvest the scallops changes the total biomass on the farm and affects the sites usage of inputs such as labor and equipment.

The objective of clam scallop aquaculture is to maximize the present value of net returns. For each culturist, this objective is achieved by selecting the appropriate spat size, culture methods, scallop density, and planting and harvest schedule. In practice, the duration of a grow-out rotation will not exceed 30 months due to increasing natural mortality but (primarily) the scallops become too big to market. Currently clam scallops are relatively expensive and large (i.e., 10-13 cm shell size).

The optimal decision to harvest and replace is based on a comparison of the opportunity costs from keeping the existing stock an additional period with the net economic gains from harvesting and replacing stock during the same period (Perrin 1972). In other words, if the net present value of harvesting and replacing in this period exceeds the expected net present value of returns associated with delaying the harvest and replacement until next period, then the "crop" should be harvested immediately and replaced (i.e., replacement is warranted).

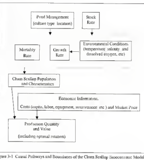

Figure 3-1 Causal Pathways and Boundaries of the Clam Scallop Bioeconomic Model

In microeconomic theory a standard assumption is that decision makers have perfect information on, for example future prices and biological growth rates. However when risk enters the decision process the theory must be extended In such cases the optimum (net present value maximizing) action depends on the probability that alternative conditions (market and or environmental) will occur In addition, the attitude of the particular decision maker toward risk would also affect the optimal decision

Any problem of decision-making under risk still involves an objective criterion Two possible criteria are 1) to maximize the expected value of profit or 2) to select the best possible action given the most pessimistic environment, which is known as a "maximin strategy (Allen et al , 1984) The approach begins by defining a number of states of nature and assuming a probability of occurrence for each All alternative actions that could be taken are specified and the payoff matrix (i e value of the outcome of each action for each state of nature) is given The decision maker selects the action that will maximize the value of his particular criterion for the given payoffs and probabilities under the worst state of nature

A general mathematical model for most types of replacement decisions is provided by the principles of dynamic programming In order to derive an optimal decision rule dynamic relationships (e g., related to asset productivity such as dynamic stock constraints) are needed. In the discrete stochastic case, when the dynamic relationships are also stochastic Howard's (1960) generic theoretical model integrated use of the transition probability matrices to define complete Markov chains These chains are determined exogenously by forces not controlled by the producer (i e., the matrix of chance failure or loss) and alternative return functions attached to each of the exogenous transition probabilities

Optimal Replacement Theory

In the case of the problem of optimal replacement, Perrin (1972) adapted a deterministic model for use in agriculture. A variable x is defined as the number of periods of remaining life until the asset is replaced For ongoing decisions regarding the continuation of the operation, the replacement concept is most appropriate for evaluating the asset(s) Each replacement asset (i.e., called challenger) must be optimized with

respect to s before it is compared with the asset already in use (i.e., called defender) and other challengers.

Perrin (1972) offers a discrete analog that is more appropriate for the case of annual harvests typical of many agricultural problems. This model in slightly altered form may be given as

$$(3.1)\quad Y(s,\infty)=\frac{1}{1-(1+r)^{-s}}\left[\sum_{t=1}^{s}(1+r)^{-t}Z(t)+(1+r)^{-s}R(s)-C\right]$$

where

$Y(s,\infty)$ = net present value of an infinite stream of revenues from an asset replaced every s period,

t = integer year,

$Z(t)$ = net revenue from the asset in year t,

$R(s)$ = salvage value of the asset in year s,

C = initial cost of the asset,

r = discount rate.

Equation (3.1) is the net present value of a single link in the continuous chain and the factor outside the brackets converts this to an infinite chain. In a recent study of a bivalve species (i.e., hard clams) the term $\sum_{t=1}^{s}(1+r)^{-t}Z(t)$ was deleted because net revenue occurs only in the replacement period s (Holman, 1993). Using this approach, the future states can be predicted in a probabilistic manner. Hence, rather than having a single net revenue state R_s, it is assumed that there are k net revenue states in each period s, $R_{k,s}$, with probability $\psi_{k,s}$. Thus, the net present value of an infinite stream of revenues from an asset replaced every s periods can be re-specified as:

$$(3.2)\quad Y(s) = \frac{1}{1-(1+r)^{-s}}\left[\sum_{k\in k^*}(1+r)^{-s}\psi_{k,s}R_{k,s} - C\right]$$

where

$\psi_{k,s}$ = probability of having state k in period s

$R_{k,s}$ = net revenue from asset in state k in period s

C = asset replacement cost,

k^* = the set of all possible states

In the case of cultured scallops gross revenue is determined by scallop size density and market price. Knowledge of growth and mortality are needed to predict scallop size and density. Markovian transition matrix can be used in order to describe growth and mortality due to genetic and environmental conditions.

If a single defender exists, equation (3.2) is maximized with respect to replacement age s and the maximum present value Y^* is calculated. If multiple challengers exist (differing by productive capability), equation (3.2) must be maximized for each replacement asset. The best challenger generates the highest Y^*. That is the culturist at each production period is faced with choosing harvesting and replacing the defender with the best challenger or allowing the asset to grow and additional period (Holman 1993). Holman (1993) shows that the replacement decision is based on a comparison of the infinite net revenue streams of each alternative as follows

$$(3.3)\quad \text{replace if } Y^* > \frac{1}{1-(1+r)^{-1}}\left[\sum_{j\in J^*}(1+r)^{-1}\delta_{j,1}D_{j,1}\right]$$

$$\text{keep if } Y^* < \frac{1}{1-(1+r)^{-1}}\left[\sum_{j\in J^*}(1+r)^{-1}\delta_{j,1}D_{j,1}\right]$$

indifferent otherwise where

δ_{ij} – the probability of having net revenue j if the defender's life is extended 1 period

D_{ij} – the net revenue j from the defender if the defender's life is extended 1 period

Equation (3 3) provides the harvest and replacement decision policy related to the cham scallop culturist. If Y^* is less than $\frac{1}{1-(1+r)^{-1}}\left[\sum_{j\neq j^*}(1+r)^{-1}\delta_{ij}D_{ij}\right]$, the product will be kept on the farm (i.e., the decision to sell is delayed for one period). The decision space defines the sets of all possible options available to the producer. Assuming that the operation will continue production in some manner, the decision space F has two elements: to keep or to harvest and replace (Holuman, 1993).

Dynamic programming is a useful optimization procedure for problems involving a sequence of interrelated decisions (Dreyfus and Law, 1977). In dynamic programming, state variables are observable or measurable conditions such as scallop size, survival and mortality, prices, etc. A stage is the time (e.g., periodic division unit) at which the system is evaluated and a policy decision required. The action chosen at each stage allows the system to change from state to state according to the processes driving changes in the state variables (Holuman, 1993).

In stochastic systems, transitions from state to state follows probabilistic patterns. A stochastic process is defined to be an indexed collection of random variables $\{X_t\}$ where the index t runs through a given set T. Often T is taken to be the set of nonnegative integers, and X_t represents a measurable characteristic of interest at time t. For example the stochastic process $X_0, X_1, X_2, \ldots$ can represent the collection of monthly inventory levels of a given product, or it can represent the collection of monthly demands for this product. The description and solution of problems involving stochastic systems is

simplified if the underlying probability process satisfies the Markovian assumption (Howard 1981)

The Markovian assumption greatly simplifies both the possible behavior of the process and the problem of specifying the process The assumption is that only the last state occupied by the process is relevant in determining its future behavior Thus, the probability of making a transition to each state of the process depends only on the state presently occupied (Howard, 1981) Equivalently, the future trajectory of a process depends only on its present state

The Markovian assumption is that the conditional probability of any future state, given decision τ and past and present states s_i is dependent only on τ and the present state of the process as depicted in equation (3 4) (Holman, 1993)

(3 4) $P\{X_{t+1} = j \mid V_t, X_t = i, F = \tau\} = P\{X_{t+1} = j \mid X_t = i, F_t = \tau\}$

where

$V_t = \{X_0, F_0, X_1, F_1 \ldots X_{t-1}, F_{t-1}\}$

X_t = state of the system at stage t

F_t = decision at stage t

One-step transition probabilities are said to be stationary and are usually denoted by p_{ij} Thus having stationary transition probabilities implies that the transition probabilities do not change in time (Hillier 1995) The existence of stationary one-step transition probabilities also implies that, for each i, j and n (n = 0, 1, 2, 3, ...)

(3 5) $P\{X_{t+n} = j \mid X_t = i\} = P\{X_n = j \mid X_0 = i\}$

for all $t = 0, 1, 2, \ldots$ These conditional probabilities are generally denoted by p_{ij}^{n} and are called n-step transition probabilities. Thus p_{ij}^{n} is just the conditional probability that the random variable X, starting in state i will be in state j after exactly n steps (Hillier 1995). These n-step transition probabilities must satisfy the following properties:

(3.6) $p_{ij}^{n} \geq 0$, for all i and j, $n=0, 1, 2, 3$,

and

$$\sum_{j=0}^{M} p_{ij}^{n} = 1 \quad \text{for all } i; n=0, 1, 2, 3$$

or equivalently,

(3.7)
$$p^{(n)} = \begin{bmatrix} p_{00}^{(n)} & p_{01}^{(n)} & \cdots & p_{0M}^{(n)} \\ p_{10}^{(n)} & p_{11}^{(n)} & \cdots & p_{1M}^{(n)} \\ \vdots & & & \\ p_{M0}^{(n)} & p_{M1}^{(n)} & \cdots & p_{MM}^{(n)} \end{bmatrix}$$

Therefore the n-step transition probability p_{ij}^{n} can be useful when the process is in state i and the probability that the process will be in state j after n periods is desired (Hillier 1995). In the transition from state i to state j the process will be in some state k after exactly v steps where v is less than n (Holman, 1993). These n-step transitions probabilities are calculated as follows:

(3.8) $$p_{ij}^{n} = \sum_{k=0}^{M} p_{ik}^{(v)} p_{kj}^{(n-v)} \quad \text{for all } i, j, n, \text{ and } 0 \leq v \leq n$$

Note that equations (3.8) are often referred to as the Chapman-Kolmogorov equations whereby $p_{ik}^{(v)} p_{kj}^{(n-v)}$ is the conditional probability that, starting from state i, the process goes to state k after v steps and then to state j in n-v steps. Summing these conditional

probabilities over all possible k must yield p_{ij}^{n}. The special cases of $v = 1$ and $v = n-1$ lead to equations

(3.9) $p_{ij}^{n} = \sum_{k=0}^{M} p_{ik} p_{kj}^{(n-1)}$

and

$p_{ij}^{n} = \sum_{k=0}^{M} p_{ik}^{(n-1)} p_{kj}$

for all i, j and n. The n-step transition probabilities can be derived from the one-step transition probabilities recursively through equation (3.9). For $n = 2$, these expressions become

(3.10) $p_{ij}^{(2)} = \sum_{k=0}^{M} p_{ik} p_{kj}$ for all i, j

From equation (3.9) the $p_{ij}^{(2)}$ are the elements of matrix $p^{(2)}$ and they are derived by multiplying the matrix of one-step transition probabilities by itself, that is

(3.11) $p^{(2)} = p \cdot p = p^{2}$

The matrix of n-step transition probabilities can be derived from the expression

(3.12) $p^{(n)} = p \cdot p \cdot p \cdot p \cdot p \cdot p \ldots = p^{n} = p p^{n-1} = p^{n-1} p$

Thus the n-step transition probability matrix can be obtained by computing the nth power of the one-step transition matrix (Hillier, 1995).

Dreyfus and Law (1977) show that the maximum expected total discounted net revenue of an asset in state i (in this case, a clam scallop grow out starting in state i) following decision policy by equation (3.3) and evolving for t time periods is:

(3.13) $Y_i^{t} = \max_{\tau}\left\{ H_{i\tau} + \rho \sum_{j=0}^{M} p_{ij}(\tau) Y_j^{t+1} \right\} \qquad i = 0, 1, 2, 3, \ldots, n$

where H_{it} is the expected return in state i at time t given action r, ρ is the discount factor or $1/(1+r)$, and $p_{ij}(r)$ is the probability of transition from state i at time t to state j at time $t+1$ when action r is taken.

Summary and Overview

Unlike capture fisheries or, in this case, chum scallop production using towing culture (where the resource is harvested from the wild at market size), aquaculture farmers have property rights and can control nearly all aspects of production (including when and how much to harvest) with precision. The major stochastic components of the process involves variable environmental conditions that can greatly affect survival and growth and, ultimately, the size and value of the harvest (i.e., markets are also an exogenous variable component). Although "wild" fisheries are also subject to the same variability, wild capture fisheries do not incur the expenses associated with starting up and maintaining a culture operation (with few alternatives) until harvest time.

The optimal replacement timing literature pioneered by Perrin (1972) suggests comparing the value of the "defender" (i.e., existing state of the stock) with the value of the "challenger" (i.e., the state following replacement of the existing stock). In this study, this basic methodology is augmented with the recent bioeconomic literature to define "value" in terms of the net present value derived from simultaneously considering the biological and economic aspects of the industry (e.g., Omal et al. 1991, Leung et al. 1993). In addition, following the use of Markovian transition probabilities for aquaculture operations (e.g., Holman, 1993; Rizzo and Spagnolo 1996), the stochastic environment is modeled to estimate expected growth. Lastly, single and multiple rotations are considered given the differences in optimal management plans found between one and

two cycle rotations in a recent study by Martinez et al (2001) Expanding on these studies, this paper will calculate transition probability matrices for two culture styles produced in two different regions The regions, in turn differ in their environmental conditions that are explained by water temperature salinity and dissolved oxygen (rather than just temperature as used previously) The relevant variables and model components will be specifically defined for use in modeling the charn scallop hanging culture in Korea In Chapters 5 and 6 following a summary of the data in the next chapter (Chapter 4)

CHAPTER 4
DATA

A bioeconomic model requires both biological and economic data. Data used in this study comes from Korea Maritime Institute (KMI), Korea National Fisheries Research and Development Institute (KNFRDI), and from an industry study conducted in 1996.

Price Information

Cham scallop wholesale prices were obtained from the Kangwon Cham Scallop Association (KCSA) and include monthly average price (won) by size category (measured in cm shell height) from 1996 through 2000 in Korea. Table 4-1 shows that price per scallop has increased with scallop size until scallops reached 14 cm. Although the price-size relationship was maintained in each year, the overall price level appeared to have peaked in 1998.

Table 4-1. Average Annual Cham Scallop Price (won) by Shell Size, 1996-2000

Year	5.00 to 5.99 cm	6.00 to 6.99 cm	10.00 to 10.99 cm	11.00 to 11.99 cm	12.00 to 12.99 cm	13.00 to 13.99 cm	Over 14.00 cm
1996	94.3	113.9	833.3	954.2	1,167.5	1,427.5	1,059.2
1997	94.1	114.6	832.7	952.1	1,163.8	1,424.2	1,061.3
1998	97.4	124.8	859.6	1,068.8	1,265.0	1,470.8	1,085.4
1999	93.8	112.4	839.6	968.3	1,195.4	1,430.4	1,084.2
2000	94.3	113.6	843.3	975.0	1,185.4	1,432.9	1,085.4

In addition to price differences by shell (animal) size prices have also varied seasonally Table 4-2 summarizes the average monthly prices Notice that prices are generally highest in the winter months (i e November through March)

Table 4-2. Average Monthly Cham Scallop Price (won) by Shell Size 1996-2000

Mon	5 00 to 5 99 cm	6 00 to 6 99 cm	10 00 to 10 99 cm	11 00 to 11 99 cm	12.00 to 12 99 cm	13 00 to 13 99 cm	Over 14 00 cm
Jan	96.2	122.2	871 0	1 011 0	1,232 0	1 463 0	1.114 0
Feb	96 4	121.2	870 6	1 020 0	1,237 0	1 463 0	1.114 0
Mar	97 0	118 8	865 0	1,012 0	1,222 0	1 454 0	1 079 0
Apr	96 8	117 0	864 0	990 0	1 196 0	1 449 0	1 076.0
May	94 0	109 6	837 4	964 0	1 177 0	1.415.0	1 053 0
Jun.	91 6	108 4	824 4	943 0	1.160 0	1 402 0	1 042 0
Jul	91 4	108 4	807 0	941 0	1,150 0	1,399 0	1 035 0
Aug	91.2	110 6	800 0	946 0	1.154 0	1 409 0	1 042 0
Sep	92 8	113 2	807 0	964 0	1,175 0	1 430 0	1 058 0
Oct.	95 6	118 2	836 0	988 0	1 196 0	1 447 0	1 083 0
Nov	96 8	120 6	855 0	1 008 0	1 219 0	1.454 0	1 098 0
Dec	97.2	122 0	863 0	1 017 0	1,227 0	1 461 0	1 107 0

The data in Table 4-2 will be used to estimate a price size relationship in the following chapter

Growth and Environmental Information

The biological data consisted of measures related to the characteristics of the water in the primary farming locations of Kojin and Chumunjin including daily

observations of water temperature, salinity, water depth, and dissolved oxygen. The available data covered the period from July 1992 through June 1995 and was obtained from the Korea National Fisheries Research and Development Institute (KNFRDI). The daily observations were averaged by month and are shown in Tables 4-3 through 4-5.

Water temperatures in both regions are lowest in the winter and early spring (December through April) and highest during the late summer months (August, September and October). On average, water temperatures are higher in Chumunjin (Table 4-3).

Table 4-3 Summary of Water Temperature (°C) by Month and Region

	Chumunjin				Kojin			
Month	Mean	St Dev	Min	Max	Mean	St Dev	Min	Max
January	8.38	1.08	7.30	10.58	6.91	0.71	6.46	7.72
February	7.45	1.54	4.83	9.60	6.89	0.99	6.32	8.04
March	7.42	1.29	6.00	9.76	7.33	0.91	6.77	8.38
April	9.38	1.88	6.70	12.01	10.63	1.82	8.60	12.10
May	12.07	1.42	9.67	14.20	11.02	1.50	9.44	12.43
June	13.06	3.12	8.49	16.20	12.12	2.48	9.32	14.02
July	16.82	1.65	13.84	19.21	14.01	1.64	12.11	15.03
August	19.51	1.27	17.78	21.40	18.03	0.70	17.29	18.67
September	19.86	1.40	17.67	21.31	17.70	0.82	16.94	18.57
October	18.23	0.90	17.32	19.64	16.47	0.25	16.22	16.73
November	14.89	0.72	14.06	15.80	13.78	0.10	13.68	13.88
December	10.92	0.99	9.43	12.20	9.41	0.18	9.21	9.57

The dissolved oxygen content of the waters in both regions exhibit seasonality with the highest average levels reported in February (Table 4-4). On average the dissolved oxygen content reaches lower and higher levels during the year in Chumunjin (5.26 to 7.17 ml/l). By comparison, the range of average monthly dissolved oxygen content in Kojin waters was 5.76 to 6.66 ml/l.

Table 4-4 Summary of Dissolved Oxygen (ml/l) by Month and Region

	Chumunjin				Kojin			
Month	Mean	St Dev	Min	Max	Mean	St Dev	Min	Max
January	6.85	0.18	6.01	7.56	6.48	0.27	6.21	6.75
February	7.17	0.27	5.61	8.11	6.66	0.29	6.38	6.96
March	6.85	0.16	6.26	7.24	6.53	0.27	6.24	6.78
April	6.44	0.20	5.63	7.36	5.76	0.47	5.21	6.04
May	6.21	0.10	5.57	6.42	6.25	0.03	6.23	6.29
June	6.04	0.16	5.39	6.64	6.21	0.11	6.12	6.34
July	5.71	0.15	4.86	6.16	6.02	0.17	5.88	6.21
August	5.26	0.23	4.14	5.91	5.99	0.29	5.68	6.24
September	5.38	0.09	4.88	5.70	5.83	0.22	5.57	5.97
October	5.92	0.14	5.32	6.38	5.88	0.45	5.47	6.36
November	6.06	0.15	5.29	6.60	5.90	0.57	5.46	6.54
December	6.27	0.09	5.71	6.49	6.28	0.28	5.98	6.52

The salinity levels of waters in both regions exhibited much less variability and seasonality than did temperature or the dissolved oxygen content (Table 4-5). In addition, the lowest and highest salinity levels were recorded during the months of September and March respectively in both regions. For the majority of months during the year, salinity levels are highest in Chumunjin.

Table 4-5 Summary of Water Salinity (0/00) by Month and Region

	Chumunjin				Kojin			
Month	Mean	St Dev	Min	Max	Mean	St Dev	Min	Max
January	33.98	0.21	33.72	34.34	33.96	0.15	33.86	34.14
February	34.08	0.24	33.80	34.41	33.89	0.40	33.54	34.32
March	34.10	0.16	33.86	34.28	34.07	0.21	33.86	34.27
April	34.06	0.16	33.81	34.28	34.01	0.19	33.88	34.22
May	33.77	0.27	33.38	34.10	33.77	0.30	33.57	34.13
June	33.73	0.35	33.26	34.20	33.49	0.06	33.44	33.56
July	33.29	0.20	33.06	33.61	33.23	0.09	33.13	33.31
August	33.18	0.63	32.40	34.22	33.03	0.78	32.35	33.88
September	32.78	0.52	32.02	33.71	32.92	0.72	32.45	33.75
October	33.04	0.37	32.64	33.68	33.01	0.53	32.65	33.62
November	33.38	0.35	32.92	33.98	33.33	0.58	32.83	33.96
December	33.65	0.26	33.31	34.02	33.66	0.34	33.34	34.01

In addition to the environmental data, information on scallop mortality and size was also obtained. Predators such as starfish are the major cause of cham scallop mortality aside from adverse environmental conditions (Park 1998). Unfortunately little empirical work exists on estimating bivalve mortality rates, especially by age. Askew (1978) linked oyster mortality to size and computed monthly mortality from annual data, using the assumption that short term rates concur with long term rates.

Mortality information for in this study used the cumulative survival rate through two years as reported by Park (1998). For cham scallops grown out using the ear suspended style, the mortality rate was determined to be 10% from age (month) 1 to age 29. For cham scallops grown out using the lantern net style, mortality was found to be 0%

from age 1 to age 10 (due to the effectiveness of barriers), but 10% from age 11 to age 29

Scallop size data was obtained from KNFRDI (1997) and included information on both regions and grow-out methods for a three-year period. Data on scallop size over time indicates in general, that larger individuals are produced in Kojin versus Chumunjin and faster growth is achieved by using the ear suspended versus lantern net method to complete the grow-out (Table 4-6)

The environmental size and mortality information was used to estimate growth functions by region and production style and calculate number of surviving scallops in each month

Farm and Cost Survey Information

The survey was conducted in 1996 and included complete information on 28 farms. Among this completed surveys, a total of 77 questions were answered. Pond size averaged 19.18 hectares (ha) but ranged from four to 50 hectares. Of that total size, 12.09 ha or 63 percent of the total pond size on average (ranging from three to 30) were used for the culture operation. Aside from characteristics of the farm questions also covered the details of input use (materials, labor), capital expenditures (trucks, vessels) and business and marketing costs (insurance, license fees, commissions). Selected data from this survey is summarized in separate sections below

Farm Owners

In terms of the education level of farm owners 34 percent just completed middle school. The majority of farm owners completed high school (54 percent). Only 14 percent completed college

Table 4-6 Average Chum Scallop Size (cm) by Month, Region, and Style 1992-1995

Month and Year	Chumunjin		Kojin	
	Lantern net	Ear-suspended	Lantern net	Ear suspended
July 1992	0.34	0.34	0.34	0.34
August 1992	0.86	0.85	0.88	0.86
September 1992	1.28	1.27	1.29	1.27
October 1992	1.97	1.95	1.98	1.96
November 1992	2.49	2.45	2.51	2.48
December 1992	3.17	3.14	3.21	3.17
January 1993	3.72	3.63	3.81	3.67
February 1993	4.14	4.08	4.15	4.06
March 1993	4.26	4.18	4.37	4.25
April 1993	4.83	4.77	4.94	4.88
May 1993	5.77	5.69	5.91	5.77
June 1993	6.43	6.33	6.47	6.34
July 1993	6.71	6.62	6.78	6.74
August 1993	7.12	7.05	7.19	7.16
September 1993	7.28	7.13	7.37	7.26
October 1993	7.68	7.54	7.77	7.63
November 1993	8.27	8.13	8.43	8.35
December 1993	8.92	8.76	9.16	9.01
January 1994	9.15	9.04	9.37	9.27
February 1994	9.42	9.34	9.33	9.27
March 1994	9.84	9.94	9.69	9.78
April 1994	10.23	10.42	9.94	10.13
May 1994	10.66	10.82	10.37	10.54
June 1994	10.83	10.94	10.75	10.87
July 1994	10.99	11.01	11.07	11.07
August 1994	11.09	11.17	11.21	11.31
September 1994	11.42	11.52	11.82	11.92
October 1994	11.44	11.53	12.04	12.13
November 1994	11.78	11.87	12.33	12.43
December 1994	12.12	12.17	12.68	12.72
January 1995	12.47	12.48	12.94	12.95
February 1995	12.61	12.62	13.02	13.08
March 1995	12.71	12.74	13.26	13.34
April 1995	13.16	13.23	13.55	13.62
May 1995	13.57	13.61	13.98	14.02
June 1995	13.85	13.88	14.34	14.37

The experience level of owners ranged from less than one year to over seven years (Figure 4-1). The majority of farmers (culturists) surveyed had five to six years of experience which is not very much but it can be explained by the fact that the industry is relatively young.

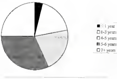

Figure 4-1. Farm Owner Experience with Cham Scallop Aquaculture

Types of Operations

The vast majority of farms surveyed were sole ownership operations (82 percent). The remaining farms (18 percent) are owned by corporations. In terms of the style of cham scallop culture used, the vast majority use lantern nets (85 percent). Only 8 percent of the farmers reported using ear-suspended technology (either single or multi) to grow-out cham scallops. The remaining respondents (7 percent) reported using both types of grow-out methods. Although all farmers grow out cham scallops to market size operations differ by the extent they participate in collecting spat (for grow-out or to sell). The majority of firms (72 percent) collect spat for grow-out and to sell to other farms to grow-out. A few firms (7 percent) collect only enough spat for their grow-out operation

The remaining firms (21 percent) do not collect spat but rather purchase all the spat they need for grow-out.

Labor Use and Expenses

In terms of the number of individuals employed in cham scallop aquaculture operations, all farms utilize at least one family member that is not paid. The average of the number of unpaid family members working on the farms is 2.61, although at least one uses eight family members. The opportunity costs associated with this labor is not accounted for in this study.

Crew sizes for boats used for cham scallop farming ranged from two to eight, averaging 4.07. For operations with multiple boats the crew size on the second boat was reported as one or two indicating the second boats may be smaller in size. The costs associated with these crews are summarized by activity in Table 4-7.

Table 4-7 Reported Labor Expenses (million won)

Description	N	Mean	St Dev	Min	Max
Pond Construction					
Full time labor	27	22.50	16.30	4.8	59.2
Temporary labor	21	2.90	5.20	0.3	24.0
Spat Operations					
Full-time labor, collection	21	20.80	19.30	1.2	85.0
Temporary labor, harvest	21	7.60	4.30	2.2	16.5
Grow-out Operations					
Full-time labor, grow-out	23	73.20	50.20	10.8	231.1
Temporary labor, final harvest	27	24.50	17.10	2.5	66.0
Meal stipend, grow-out	28	17.20	11.60	1.8	51.8

Labor expenses for full-time and temporary employees for pond construction averaged approximately 25.4 million won. For comparison, labor expenses for spat

operations averaged 28.4 million won and those for grow-out activities averaged 97.7 million won (excluding 17.2 million won for meals).

Start-up Costs

The fixed or sunk costs associated with beginning a charn scallop aquaculture operation are summarized in Table 4-8. The expenses are itemized by spat collecting and grow-out activities. The start-up costs for spat collecting are comprised of ropes (averaging approximately 780,000 won), floats (averaging approximately 2,274,000 won), collecting equipment (2.2 million won), and other (averaging approximately 724,000 won in total for buoys, sinkers, and anchors).

Grow-out expenses contain costs for similar items but also include machinery that is relatively expensive. For example, intermediate, ear suspended and general grow-out machinery costs averaged 17.8, 11.3, and 33.4 million won, respectively. Total average costs for ropes and floats was approximately 7.8 and 8.9 million won, respectively. Other expenses for buoys, sinkers, and anchors averaged approximately 5.8 million won in total. The cost of the primary truck used in the operation averaged 5.6 million won but ranged from 2.5 to 22.2 million won.

Note that the approximate totals (on average) could overestimate the costs associated with a single farm if the farm did not incur that expense. To approximate the total for the responding firms, the means could be multiplied by the number of reporting farms. The magnitude of the standard deviations relative to the means indicates the extent of variability in charn scallop aquaculture farms in Korea in terms of start-up expenses.

Table 4-8 Start-up Expenses for Spat Collection and Grow-out (thousand won)

Item	N	Mean	Std Dev	Min.	Max.
Spat Collection					
gan seong ropes	22	184.2	119.8	35.2	446.4
surface ropes	22	29.1	23.9	1.7	81.6
jung-chung ropes	22	119.0	105.4	6.0	453.4
collecting ropes	22	391.5	304.6	76.9	1107.1
anchor ropes	22	160.2	116.9	3.7	559.8
surface floats	22	73.5	56.7	8.3	248.6
jung-chung floats	22	2,200.0	6,100.0	0.0	30,000.0
buoys	20	195.3	177.0	60.0	828.6
sinkers	22	226.7	136.4	53.2	500.0
collecting equipment	22	2,200.0	4,400.0	120.0	18,000.0
anchors	22	301.9	189.9	60.0	903.6
Grow-out					
gan seong ropes	28	1,230.3	988.7	35.2	3,749.0
surface ropes	28	213.5	197.9	15.6	734.7
jung-chung ropes	24	966.8	931.2	54.0	4,080.4
grow-out ropes	28	2,382.5	2,939.7	172.4	9,085.6
intermediate ropes	24	583.1	761.2	64.8	3,587.7
ear suspend ropes	3	1,123.5	1,640.8	77.4	3,014.6
anchor ropes	28	1,337.9	1,066.6	33.5	5,037.9
surface floats	28	691.5	929.7	74.9	4,717.4
jung chung floats	26	8,172.4	5,857.5	179.7	26,617.5
buoys	24	1,936.2	2,506.2	300.0	11,880.0
sinkers	28	1,615.4	1,139.8	409.5	4,500.0
intermediate machine	24	17,800.0	10,600.0	800.0	4,800.0
grow-out machine	28	33,400.0	35,900.0	900.0	16,500.0
ear suspend machine	3	11,300.0	18,500.0	500.0	3,300.0
drill machine	9	312.2	139.1	80.0	500.0
anchors	28	2,331.4	1,659.5	175.5	8,132.8
primary truck	22	5,627.3	4,496.3	2,500.0	22,166.7

In addition, the purchase price of the primary vessel averaged 19.9 million won but ranged from 9 to 34 million won. The purchase price of the second vessel (if applicable) ranged from 12.5 to 38 million won, averaging 22.5 million won; only seven firms reported owning a second vessel.

Miscellaneous Expenses

All clam scallop aquaculture operations paid a 12,000 license fee. In addition, all clam scallop aquaculture operations that collected spat paid 10,000 won for a permit. Itemized expenses are summarized in Table 4-9. On average, repair expenses totaled 1.56 million won during spat collection and 6.84 million during grow-out. Miscellaneous sales expenses (including washing, boxing, etc.) totaled 15.6 million won. Product sales fees (commission and transportation) averaged 7.2 million won in total. Aside from direct expenses, it is noteworthy that many firms have outstanding loans. Nearly all firms (25 of the 28 respondents) had a loan from a fishery cooperative union and the average of these loans was 150.5 million won (ranging from 30 to 1,000 million won).

Other variable costs to consider include the fuel used in spat collecting (if applicable) and grow-out. On average, fuel expenses totaled 0.6 million won during spat collecting and 4.8 million won during grow-out. The later expenses exhibited a relatively high degree of variation, however, as reported fuel expenses for grow out ranged from 0.5 to 12.1 million won.

The final miscellaneous expense discussed here is the cost of renting a boat. Boat rental fees for spat collection averaged 0.9 million won. Since this expense reportedly ranged from 0.1 to 2.1 million won, there appears to be a difference in how operations are conducted within the industry. Boat rentals for grow-out activities were much higher

averaging 13.2 million won Like with spat collecting boat rental fees during grow-out varied significantly (from 0.3 to 189.0 million won) indicating heterogeneity between operations.

Table 4-9 Miscellaneous Expenses (million won)

Description	N	Mean	St Dev	Min	Max.
Repairs spat collection	22	1.56	1.17	0.2	4.10
Repairs grow-out	28	6.84	4.42	1.07	16.40
Product sales commission	25	3.21	5.85	0.04	24.00
Product transportation	22	4.03	4.15	0.05	18.00
Miscellaneous sale expenses	26	15.60	14.90	0.60	60.00
Purchase scallop spat	6	9.80	1.80	7.10	12.00
Office expenses	25	2.86	1.67	0.30	6.00
Insurance	21	4.25	4.74	0.05	18.00
Loans					
Fishery cooperative union	25	150.50	200.00	30.00	1,000.00
Bank	9	100.00	96.10	15.00	300.00
Individuals	14	136.40	182.20	20.00	700.00
Vessel Expenses:					
Spat Collection Fuel	22	0.61	0.40	0.06	1.35
Spat Collection Boat Rental	21	0.89	0.69	0.12	2.10
Grow-out Fuel	28	4.77	3.46	0.54	12.15
Grow-out Boat Rental	28	13.20	34.90	0.30	189.00

Summary

In summary spat collecting costs averaged 41 million won in 1996 The majority of spat collecting expenses were attributed to employee wages (31 million won or 77 percent) Initial equipment costs averaged 6 million won or 15 percent of total spat collecting expenses For grow-out, expenses averaged 293 million won in 1996 The majority of average grow-out expenses were from employee wages (137 million won or

47 percent) and initial capital expenses for machinery (62 million won or 22 percent). The average cost of initial equipment expenses for grow-out, including the machinery expense totaled 91million won or 31 percent of total grow-out costs. Thus in terms of initial equipment expenditures grow-out activities cost nearly twice as much as spat collecting.

The data obtained from the survey covered 28 farms. For comparison there were approximately 54 farms operating in 1996. Thus, the survey covered 52 percent of the total population of producers. The survey results are considered representative. Even though there are 54 cham scallop aquaculture farms, the 28 farms that this research focuses on all have farming areas larger than 3 hectares. The remaining 26 farms have the farming area smaller than 3 hectares. Consequently, they have minimal impact on the total cham scallop production of Kangwon province. In other words, the 28 farms studied in this research account for the over 90% of total cham scallop production of the province and represent the industry well.

The costs summarized in the previous paragraph and preceding section will be used to estimate fixed and variable costs associated with each type of activity and culture style. This information will be combined with the estimated production and price functions that will be estimated using the environmental data (water temperature, salinity and dissolved oxygen levels), scallop size data, and price data described earlier. The specifics regarding the estimation of these functions will be described in the next chapter.

CHAPTER 5
SUBMODEL SPECIFICATIONS AND RESULTS

The objective of the model was to maximize the present value of net returns to the firm's resources over the planning horizon. The specification of the objective function requires information on revenues and costs. Revenues are calculated as price times quantity so we need a price function and a means to calculate harvest quantity. Harvest quantity, in this case, will involve an estimation of a growth function for individual scallops and assumptions about the initial biomass (i.e. quantity of spat planted) and natural mortality rates. On the cost side, information is needed on both fixed costs (costs that are independent of production volumes such as initial set up expenses, insurance, and license fees) and variable costs (costs that are incurred as a result of production such as cost per hectare or cost per kg). This chapter will describe the estimation of the price, growth, and cost functions.

Price Functions

From the observed price data (Tables 4-1 and 4-2), cham scallop prices appear to be determined by scallop size (cm shell length) and season (month of sale). Since this was the case with the shrimp fishery modeled by Tian et al. (1993), a similar functional form is initially specified:

(5.1) $P = \alpha_0 + \alpha W + \alpha_2 W^2 + \alpha_3 DS + \alpha_4 DW$

where P is scallop price (won) per shell, W is cham scallop weight (kg), and DS and DW are dummy variables for the summer ($DS = 1$ if sales occur May through September, DS

= 0 otherwise) and winter (DW = 1 if sales occur December through February. DW = 0 otherwise) months, respectively. Weight is obtained by using an equation that converts size in cm to weight in kg as estimated by Park (2001), specifically

(5.2) $\quad W = 0.005664\ e^{0.3041*cm}$

Using this equation, a scallop measuring 10 cm would weigh 0.118 kg.

Estimation of the equation (5.1) using ordinary least squares and 420 observations (monthly observations over five years and 7 sizes) produced the following empirical model (standard errors are contained in the parenthesis below each estimated coefficient):

(5.3) $\quad P = -197.4 + 9{,}232.1W - 13{,}764.8W^2 - 31.9\,DS + 13.7\,DW$

$\qquad\qquad (8.34) \quad (73.91) \quad (149.65) \qquad (6.87) \qquad (7.83)$

Using this equation, a 0.118 kg scallop would sell for 703.5 won. The magnitude of the estimated coefficients relative to the standard errors indicates that all coefficients except for the dummy on winter months are statistically significant at the 1% level. The dummy variable for the winter months is, however, statistically significant at the 10% level. Overall, equation (5.3) explained 98% of the observed price variation indicating an extremely good fit. Note that the price equation could have been estimated using size instead of weight; weight was incorporated at this point since it is a more traditional representation and will be used later to determine production levels.

The model excluded information on supplies since aggregate monthly production data was not available. Note, however, that there are no imports for this product (which is sold predominantly in fresh form and is perishable) and no "wild" landings during the time series covered (recall from Chapter 2 that sowing culture landings were first reported in 2000). Monthly dummy variables were also tested, but none were statistically

significant when and F-value was used to compare this model with model (5.1). The test could not reject the hypothesis that the coefficients on the monthly dummies were zero (i.e., it supported the use of the restricted model). Yearly dummy variables were also included but an F test revealed that their inclusion was not justified either. In summary, the estimated price model is similar to other models that use the characteristics of the product to explain price, similar to hedonic analysis. Such models have been successfully used to model prices in several fisheries (e.g., Gates, 1974; Larkin and Sylvia, 1999).

Growth Functions

Obtaining a reliable growth function is an integral part of deriving the optimal harvesting strategy for any aquaculture operation (Tian et al., 1993). To date, however, no studies have estimated growth equations for the cham scallop species. The primary factors believed to influence growth have, however, been identified by Park (1998). This study found that cham scallop size is primarily affected by water temperature (T), dissolved oxygen content (O), and salinity levels (S) and that growth rates vary by scallop age (A). If so, time series data on cham scallop size as measured by shell height or length (cm) can be used with the variables T, O, S and A to estimate an empirical model of growth. The model would allow for the testing of the growth effects (changes in the size of the individual scallop) associated with each attribute. In general, higher levels or values of each environmental variable (T, O and S) are hypothesized to increase the size of scallops (promote growth) following the work of Park (1998). Growth effects may also be nonlinear; for example, growth rates may slow with age.

Since some of the independent variables, especially those associated with the environment, may be correlated (which would affect the ability of the econometric model

to estimate accurate parameter values), correlation coefficients were calculated for each region (Table 5-1). Results show that there is a relatively high degree of linear association between water temperature and both dissolved oxygen and salinity levels in the Chumunjin region.

Table 5-1 Correlation Between the Explanatory Variables in the Growth Function by Region

Region	Variable	A	T	O
		Variable		
Chumunjin	T	-0.332	1.000	
	O	0.197	-0.868	1.000
	S	0.341	-0.839	0.704
Kajin	T	-0.232	1.000	
	O	-0.018	-0.641	1.000
	S	0.366	-0.720	0.193

If there appears to be multicollinearity problems in the model (i.e., high explanatory power of the model but few statistically significant independent variables) then corrective procedures will be considered. Corrective procedures are not implemented *a priori* since (1) the multicollinearity may not cause estimation problems (2) the correlation coefficients only measure linear relationships when a non linear model may perform best, and (3) coefficient estimates are desired for each variable in order to incorporate the probabilities associated with each environmental state (and evaluate the effect of stochastic growth).

Although some information is available on the factors that affect ehan scallop growth and the nature of their individual effects, the true functional form of the growth function is unknown. In the case of bivalve species in general, linear specifications

(Longh, 1975) and log-linear specifications (Holsman 1993 Bosch et al 1989) have been used most frequently Tian et al (1993) also compared specifications for shrimp growth that included nonlinear explanatory variables such as logarithmic quadratic and interactions Since the true specification is unknown for cham scallops the following five functional forms were specified

(5 4) Linear

$$G = \beta_0 + \beta_1 A + \beta_2 T + \beta_3 O + \beta_4 S \quad \text{(G1)}$$

(5 5) Log reciprocal

$$\ln G = \beta_0 + \beta_1\left(\frac{1}{A}\right) + \beta_2\left(\frac{1}{T}\right) + \beta_3\left(\frac{1}{O}\right) + \beta_4\left(\frac{1}{S}\right) \quad \text{(G2)}$$

(5 6) Double log

$$\ln G = \beta_0 + \beta_1 \ln A + \beta_2 \ln T + \beta_3 \ln O + \beta_4 \ln S \quad \text{(G3)}$$

(5 7) Polynomial

$$G = \beta_0 + \beta_1 A + \beta_2 A^2 + \beta_3 T + \beta_4 T^2 + \beta_5 O + \beta_6 O^2 + \beta_7 S + \beta_8 S^2 \quad \text{(G4)}$$

(5 8) Linear with interactions

$$G = \beta_0 + \beta_1 A + \beta_2 T + \beta_3 O + \beta_4 S + \beta_5 A\ T + \beta_6 A\ O + \beta_7 A\ S \quad \text{(G5)}$$

The number in parenthesis to the right will be used to help identify the functional forms for growth (G) which is measured as the ratio of final size to initial size in the tables that summarize the empirical results

Given that there are data from multiple regions and culture methods associated with cham scallop production in Korea, this information needs to be considered For example according to Park (1998) growth is affected by environmental attributes which vary by region (Tables 5-3 through 5-5) The two culture styles which use different

technologies may also affect scallop growth rates To account for regional and culture method effects, dummy variables can be included or separate regressions can be estimated Since the use of dummy variables would entail the inclusion of several additional variables in order to estimate the regional growth effects associated with the environmental variables (i e., include dummy interaction variables) the five alternative growth function specifications were estimated for each region and culture method to simplify the analysis The data used to estimate each model was summarized in Tables 4-3 through 4-6 (i e., temperature, dissolved oxygen, salinity and scallop size) Note that scallop age is synonymous with time as measured in months (36 months in total) Results are presented in Tables 5 2 through 5 5.

There are several methods for objectively evaluating and comparing the fit of alternative model specifications. An F-test for the overall specification found that all models were statistically significant at the 5% level Although F-values cannot be compared directly it is important to know that all are satisfactory in terms of explaining chain scallop growth One of the simplest measures of the explanatory power of the model the adjusted R^2 measure can only be used for models with identical dependent variables Thus, the adjusted R^2 can be used to compare models (G1), (G4) and (G5) That comparison revealed that among these three models, (G4 polynomial) was the best for Chumunjin and (G5 linear with interactions) was the best for Kojin irrespective of the culture style. Similar to the adjusted R^2 value the root mean square error is only comparable if the dependent variable is the same For models (G1) (G4), and (G5) this measure supported the best model based on the adjusted R^2 values

Table 5-2. Empirical Growth Models for the Ear-suspended Style in Chumunjin

Variable	Model (G1)	(G2)	(G3)	(G4)	(G5)
Intercept	5.988	0.480	7.557	635.017*	21.486*
	(5.897)	(0.933)	(7.139)	(231.365)	(16.547)
A	-0.013*			-0.059*	-0.917*
	(0.004)			(0.013)	(0.226)
T	0.006			0.071	
	(0.022)			(0.071)	
O	0.033			0.386	-0.013
	(0.308)			(0.477)	(0.154)
S	-0.146			-37.397*	-0.596*
	(0.143)			(13.763)	(0.175)
1/A		1.731*			
		(0.379)			
1/T		-0.104			
		(0.452)			
1/O		0.167			
		(0.636)			
1/S		18.448			
		(31.525)			
A.T					
A.O					3.1E-06
					(0.006)
A.S					0.027*
					(0.007)
*ln*A			-0.186*		
			(0.025)		
*ln*T			0.038		
			(0.104)		
*ln*O			-0.076		
			(0.262)		
*ln*S			1.909		
			(2.801)		
A^2				0.001*	
				(0.0003)	
T^2				-0.004	
				(0.003)	
O^2				-0.029	
				(0.039)	
S^2				0.551*	
				(0.204)	
Adj. R^2	0.316	0.926	0.676	0.650	0.620
F	5.928	186.906	18.696	8.886	12.187
U^M	1.19E-30	1.02E-31	1.02E-28	1.24E-24	1.88E-28
U^R	5.14E-28	1.32E-28	2.38E-24	5.18E-17	1.93E-22

Note: Standard errors are in parentheses. A single asterisk indicates significance at the 5% level

Table 5-3 Empirical Growth Models for the Ear-suspended Style in Kojin

	Models				
Variable	(G1)	(G2)	(G3)	(G4)	(G5)
Intercept	7.700	1.254	7.9471	433.446*	10.062*
	(5.403)	(1.037)	(7.007)	(149.916)	(5.283)
A	-0.011*			0.042*	-0.591
	(0.004)			(0.017)	(0.449)
T	0.0006			0.079	0.012
	(0.019)			(0.071)	(0.041)
O	0.121			0.747	0.175
	(0.136)			(1.988)	(0.335)
S	-0.212*			25.911*	-0.537*
	(0.112)			(9.059)	(0.223)
1/A		1.719*			
		(0.103)			
1/T		-0.885*			
		(0.505)			
1/O		-1.467			
		(1.196)			
1/S		-32.852			
		(30.180)			
A·T					-0.0007
					(0.002)
A·O					-0.009
					(0.014)
A·S					0.019
					(0.012)
*ln*A			-0.166*		
			(0.026)		
*ln*T			0.025		
			(0.104)		
*ln*O			0.273		
			(0.412)		
*ln*S			2.261		
			(1.831)		
A^2				0.0007*	
				(0.0004)	
T^2				0.003	
				(0.003)	
O^2				-0.063	
				(0.165)	
S^2				0.386*	
				(0.136)	
Adj. R^2	0.410	0.931	0.700	0.640	0.656
F	6.906	116.212	20.867	8.554	10.269
U^M	3.37E-29	2.46E-29	5.71E-28	2.43E-25	5.04E-28
U^R	2.58E-26	2.40E-27	1.07E-23	5.27E-18	5.37E-23

Notes: Standard errors are in parentheses. A single asterisk indicates significance at the 5% level.

Table 5-4 Empirical Growth Models for the Lantern Net Style in Chumunjin

	Models				
Variable	(G1)	(G2)	(G3)	(G4)	(G5)
Intercept	6.122	0.398	7.849	648.524*	21.941*
	(5.185)	(0.931)	(7.198)	(235.629)	(5.248)
A	-0.013*			-0.060*	-6.931*
	(0.004)			(0.013)	(0.230)
T	0.006			0.075	
	(0.021)			(0.072)	
O	0.037			0.409	0.012
	(0.105)			(0.483)	(0.157)
S	0.151			38.255*	-0.610*
	(0.146)			(13.957)	(0.178)
1/A		1.738*			
		(0.094)			
1/T		-0.172			
		(0.451)			
1/O		0.049			
		(0.635)			
1/S		15.888			
		(31.442)			
A·T					
A·O					3.5E-87
					(0.006)
A·S					0.027*
					(0.007)
*ln*A			-0.186*		
			(0.025)		
*ln*T			-0.030		
			(0.105)		
*ln*O			-0.053		
			(0.264)		
*ln*S			2.009		
			(2.018)		
A^2				0.001	
				(0.0003)	
T^2				-0.004	
				(0.003)	
O^2				0.031	
				(0.040)	
S^2				0.564*	
				(0.207)	
Adj. R^2	0.315	0.927	0.676	0.651	0.618
F	5.903	109.493	18.710	8.936	11.991
U^M	1.15E-30	2.56E-30	5.45E-28	1.34E-25	1.45E-27
U^R	8.33E-28	2.01E-29	2.88E-24	5.31E-17	1.94E-22

Notes: Standard errors are in parentheses. A single asterisk indicates significance at the 5% level

Table 5-5 Empirical Growth Models for the Lantern Net Style in Kojin

Variable	Models (G1)	(G2)	(G3)	(G4)	(G5)
Intercept	7.758	1.348	7.823	442.164*	18.138
	(5.591)	(1.093)	(7.245)	(158.703)	(9.868)
A	0.011*			-0.043*	-0.602
	(0.004)			(0.018)	(0.478)
T	0.001			0.079	0.013
	(0.019)			(0.076)	(0.043)
O	0.129			0.808	0.202
	(0.142)			(2.104)	(0.355)
S	-0.215			26.443*	-0.545*
	(0.117)			(9.590)	(0.237)
1/A		1.745*			
		(0.108)			
1/T		-0.924			
		(0.533)			
1/O		1.629			
		(1.261)			
1/S		35.064			
		(31.822)			
A T					-0.0007
					(0.002)
A O					-0.010
					(0.014)
A S					0.020
					(0.012)
*ln*A			-0.167*		
			(0.027)		
*ln*T			0.038		
			(0.107)		
*ln*O			0.309		
			(0.426)		
*ln*S			2.246		
			(1.893)		
A^2				0.0008	
				(0.0005)	
T^2				-0.003	
				(0.003)	
O^2				-0.068	
				(0.174)	
S				0.394*	
				(0.144)	
Adj R^2	0.397	0.926	0.690	0.621	0.635
F	6.598	107.618	19.944	7.954	9.439
U^{M}	0	2.46E-30	3.55E-28	5.89E-25	0
U^{N}	8.77E-27	3.40E-27	9.59E-24	5.92E-18	5.14E-23

Notes: Standard errors are in parentheses. A single asterisk indicates significance at the 5% level.

Another method for comparing all models is to use Theil's inequality coefficients, which measure the mean square error in relative terms. These coefficients decompose Theil's inequality (U) into three components: the bias proportion (U^M), regression proportion (U^R) and the disturbance proportion (U^D). Since these proportions sum to one they can be used to compare the forecasting ability of different model specifications.

The bias proportion reflects how far the mean of the forecast is from the mean of the actual series. The regression proportion, also known as the variance proportion, represents the percentage variation in actual and forecast errors. The disturbance proportion, also known as the co-variation proportion, reflects the remaining unsystematic projection errors. This latter proportion, which is due to imperfect co-variation, should be the major source of discrepancy in actual and forecast errors. In other words, if the model's projection is accurate, the bias and regression proportions should be small. Thus the bias and regression proportions (U^M and U^R respectively) can be used to assess and compare the adequacy of the five estimated growth models in terms of forecast accuracy (Tian et al., 1993).

Theil's inequality coefficient can be decomposed as follows (Theil, 1966):

$$(5.9)\quad \frac{1}{n}\sum(PS-OS)^2 = \left(\overline{PS}-\overline{OS}\right)^2 + \left(SD_{PS}-rSD_{OS}\right)^2 + \left(1-r^2\right)SD_{OS}^2$$

where PS and OS are the predicted and observed sizes, respectively, from the least-squares regressions. SD is the associated standard deviation and r is the correlation coefficient between PS and OS.

By dividing each component of Theil's inequality coefficient by the mean square error, the bias proportion (U^M), regression proportion (U^R) and disturbance proportion (U^D) are found.

$$(5.10)\quad U^M = \frac{\left(\overline{PC} - \overline{OC}\right)^2}{\frac{1}{n}\sum\left(PC_i - OC_i\right)^2}$$

$$(5.11)\quad U^R = \frac{\left(SD_{PC} - rSD_{OC}\right)^2}{\frac{1}{n}\sum\left(PC_i - OC_i\right)^2}$$

$$(5.12)\quad U^D = \frac{\left(1 - r^2\right)SD_{OC}}{\frac{1}{n}\sum\left(PC_i - OC_i\right)^2}$$

Model comparisons generally involve the examination of only U^M and U^R given the three measures sum to one (Theil et al., 1993). Overall, the U^M measure identified either the (G1) linear or (G2) log reciprocal model as best since they had the lowest percentage difference between the means of the predicted (forecast) and observed values. The U^R measure identified the (G2) log reciprocal model has having the lowest percentage variation in the predicted and observed errors across both regions and culture styles. Note that these models are not the same models are predicted using the linear model decision tools because the log reciprocal model could not be included in these comparisons. Since the log reciprocal model performed best in six of the eight categories (i.e. the U^M and U^R values for the estimated growth equations by region and culture style), and in the other two it was the second best model, the (G2) specification is used to predict growth for both regions and culture styles in the optimizations and simulations that follow in the next chapter.

Cost Functions

Total costs include fixed and variable costs. For aquaculture, costs are typically estimated using data from a single rotation (which could be shorter or longer than one year). Although costs studies can be quite detailed in terms of the number of variables

included, the estimation of a cost function only requires use of the total cost estimate and variable(s) that determine the magnitude of variable costs. Table 5-6 summarizes the expenses that have been included in the total cost estimate in several recent studies covering a variety of species (i.e., shrimp, flounder, and sea bass).

Table 5-6. Components of Total Costs used to Estimate Aquaculture Cost Functions

Study	Total Cost (*TC*) Components
Martinez et al. (2001)	cycle seed, fertilizer, labor, contingency
Tian et al. (2000)	maturation tanks, hatchery tanks, nursery ponds, grow ponds
Tian et al. (1993)	energy, labor, stocking, feeding
Hochman et al. (1990)	energy, labor, stocking, feeding
Rizzo et al. (1996)	energy, stocking, feeding, pumping, aux. oxygen, fixed costs
Zucker et al. (1999)	building, equipment, vehicle, energy, labor, stocking, feeding, maintenance, waste, general and administrative

Although the studies provide some information as to the types of expenses that should be included, no study has examined the case of churn scallops, which do not require hatching tanks or feeding. This is notable since, for example, feed costs can be one of the major expenses associated with closed aquaculture systems.

The survey data summarized in Chapter 4 will be used to estimate fixed and variable costs associated with churn scallop hanging culture in Korea. The total cost variable needed to estimate a basic cost function is comprised of fixed costs per cycle associated with grow out and the variable costs associated with maintenance during the grow-out period and harvest and marketing expenses. The fixed costs were calculated from the start-up expenses for grow-out itemized in Table 4-8 (i.e., ropes, floats, buoys, machinery, anchors, and a boat) and similar lump-sum initial costs such as insurance and license fees (Table 4-9). The variable expenses included labor associated with grow-out

and harvest (Table 4-7), spot purchase costs, fuel, repairs, and product sales and transportation charges.

In practice no distinction is made between fixed and variable costs for purposes of deriving an estimate of total costs only the total cost figure is needed for each operation. The primary decision that has to be made concerns the appropriate measure of variable cost. The two most frequently used measures are production volume and farm size which produce estimates of the cost per kg or cost per ha, respectively. Although either specification may be appropriate for a given objective, this study will utilize production volume as the explanatory variable in order to coincide with the estimate of final size (growth) that will be used to estimate total revenue.

Given that production can occur in different regions using different technologies, it is likely that these factors could affect costs. To examine cost differences (fixed and variable) by culture style and area (region or location of farm), two dummy variables are created DC_s and DC_r. The culture style is distinguished by index s, which equals 1 for lantern nets and 0 for ear-suspended. The culture area is distinguished by index r, which equals 1 for Chunmunjin and 0 for Kojin. These dummy variables are then multiplied by the production volume to obtain estimates of variable costs that differ by style and region.

Table 5-7 summarizes the cost data used to estimate alternative cost functions. The average production (Q) per farm was 70,284 kg although it ranged from 18,000 to 170,000 kg. The majority of operations (90 percent) used the lantern net culture style. An equal number of operations were in each region. Recall that there were 28 total farms included in the survey.

Table 5-7 Statistical Summary of Survey Data used in the Cost Function

Variable	Description	Mean	St Dev	Min	Max.
TC	Total Cost (mil won)	284.7	178.1	44.3	917.7
Q	Production (kg)	70,284.0	42,156.0	18,000.0	170,000.0
DC_s	Culture Style	0.9	0.4	0.0	1.0
DC_a	Culture Area	0.5	0.5	0.0	1.0
$Q\,DC_s$	Interaction	51,546.0	39,293.0	0.0	170,000.0
$Q\,DC_a$	Interaction	34,451.0	48,017.0	0.0	159,667.0

To get a general impression of the relationship of production levels to total costs, each data point from the data summarized in Table 5-7 is plotted in Figure 5-1 below. This figure shows, as would be expected, that total costs increase with production levels and the increase may be non-linear.

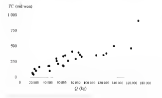

Figure 5-1 Reported Production (Q) and Total Cost (TC) Data from 1996 Farm Survey

Overall, several alternative cost functions were estimated and compared. The alternatives varied by functional form of the independent variables (i.e., Q or ha as linear or polynomial) and inclusion of dummy and interaction terms. Since the focus for this study is on the variable costs associated with total landings (production) and the higher order polynomial models performed better overall, only these models are compared here. Appendix A contains the additional model runs (using Q and/or ha as linear and/or polynomial forms and with and without inclusion of dummy and interaction terms) and associated discussion.

Using the reported landings (Q), a cost function can be estimated to test the statistical significance of the fixed and variable cost per unit of landings. Generally, quadratic (Q^2) and cubic (Q^3) functions are used since they exhibit desirable theoretical properties (Tian et al., 1993). All second-degree curves (i.e., average total cost, average variable cost, and marginal cost) first decline and then increase as output is expanded. Thus, a cubic function provides a reasonable approximation to virtually any cost function (see Tveteras, 2002 and references cited therein for specification and use of this type of model for aquaculture). Including dummy variables for culture type and geographical area (DC_t and DC_a, respectively) and interactive variables between the dummies and landings, the following models were specified, estimated, and compared:

(5.13) $TC = \eta_0 + \eta_1 Q + \eta_2 Q^2 + \eta_3 Q^3 + \eta_4 DC_t + \eta_5 DC_a + \eta_6 Q\ DC_t + \eta_7 Q\ DC_a$ (C1)

(5.14) $TC = \eta_0 + \eta_1 Q + \eta_2 Q^2 + \eta_3 Q^3 + \eta_4 DC_t + \eta_5 DC_a + \eta_6 Q\ DC_t$ (C2)

(5.15) $TC = \eta_0 + \eta_1 Q + \eta_2 Q^2 + \eta_3 Q^3 + \eta_4 DC_t + \eta_5 DC_a$ (C3)

(5.16) $TC = \eta_0 + \eta_1 Q + \eta_2 Q^2 + \eta_3 Q^3 + \eta_4 DC_a + \eta_5 Q\ DC_a$ (C4)

(5.17) $TC = \eta_0 + \eta_1 Q + \eta_2 Q^2 + \eta_3 Q^3 + \eta_4 DC_a$ (C5)

(5.18) $TC = \eta_0 + \eta_1 Q + \eta_2 Q^2 + \eta_3 Q^3 + \eta_4 DC_s + \eta_5 Q \cdot DC$ (C6)

(5.19) $TC = \eta_0 + \eta_1 Q + \eta_2 Q^2 + \eta_3 Q^3 + \eta_4 DC_s$ (C7)

(5.20) $TC = \eta_0 + \eta_1 Q + \eta_2 Q^2 + \eta_3 Q^3$ (C8)

The parameter η_0 is the common or base level fixed cost, variables costs are calculated using (at least) the η_1, η_2, and η_3 parameters. The remaining parameters, η_4 through η_7, serve to adjust the fixed or variable cost for culture style or area differences. The number in parenthesis to the right will be used to help distinguish among the alternative cost functions (C) in the tables summarizing the empirical results.

Table 5.8 summarizes the correlation coefficients between the independent variables. High correlations would increase the likelihood of multicollinearity problems in estimations. As expected the correlations among the Q variables and, to a lesser extent, among the interaction terms are high and may be problematic.

Table 5-8. Correlations Between Independent Variables

	Q	Q^2	Q^3	DC_s	DC_a	$Q \cdot DC_s$	$Q \cdot DC_a$
Q^2	0.965	1					
Q^3	0.905	0.983	1			symmetric	
DC_s	-0.600	-0.602	-0.551	1			
DC_a	-0.033	0.023	0.036	-0.408	1		
$Q \cdot DC_s$	0.327	0.273	0.256	0.545	-0.521	1	
$Q \cdot DC_a$	0.507	0.499	0.453	-0.837	0.731	-0.480	1

Table 5.9 shows the parameter estimates and associated standard errors for cost models (C1) through (C8) and the adjusted R^2, F, and RSS values for each. The overall F statistics ranging from 25.96 to 45.66 indicate that no model can be rejected on the basis of the overall specification.

Table 5-9 Total Cost Function Regression Results

Variable	Model C1	C2	C3	C4	C5	C6	C7	C8
η_0	403.0	372.2	-167.6	-143.2	-85.2	350.9	-201.2*	-150.5
	(319.1)	(262.6)	(100.8)	(90.8)	(92.2)	(255.0)	(77.4)	(79.3)
Q	0.0055	0.0061	0.009*	0.012*	0.012*	0.006	0.009*	0.014*
	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Q^2	-9.8E-8	-1.0E-7	-7.5E-8	-1.0E-7*	-1.2E-7*	-1.0E-7*	-7.8E-8	-1.4E-7*
	(5.6E-8)	(5.3E-8)	(5.6E-8)	(4.9E-8)	(5.2E-8)	(5.1E-8)	(5.4E-8)	(4.8E-8)
Q^3	4.2E-13*	4.3E-13	3.1E-13	4.1E-13	4.7E-13*	4.4E-13*	3.2E-13	5.6E-13*
	(2.1E-13)	(2.0E-13)	(2.1E-13)	(1.8E-13)	(1.9E-13)	(1.9E-13)	(2.1E-13)	(1.8E-13)
DC_r	-474.4	-455.0	106.1*			-450.4	120.1*	
	(287.9)	(261.9)	(61.9)			(257.0)	(55.3)	
DC_n	-26.1	13.6	-16.9	56.6	-39.7			
	(75.8)	(29.2)	(31.6)	(54.4)	(29.8)			
$Q{\cdot}DC_r$	0.005*	0.004*				0.004*		
	(0.0025)	(0.002)				(0.002)		
$Q{\cdot}DC_n$	0.0002			0.0014*				
	(0.0013)			(0.0007)				
Adj R^2	0.866	0.872	0.850	0.858	0.838	0.877	0.855	0.832
F	25.96	31.75	31.63	33.54	35.79	39.46	40.73	45.66
RSS	84,895	85,032	104,584	99,308	118,533	85,913	105,940	127,661

Notes: Standard errors are in parentheses. A single asterisk indicates significance at the 5% level.

Using the adjusted R^2 value to compare models, which is valid given the dependent variable is identical in each model (unlike with the growth models), specification (C6) is identified as the model that explains the highest percentage variation in the reported total cost estimates. However, the adjusted R^2 values varied only slightly and all would be considered high since they ranged from 83.2% to 87.7%.

An alternative way to identify the best model is to conduct a series of F tests among the nested and non nested (restricted and unrestricted) models to assess whether specific variables should be included. This statistic is calculated as follows:

$$(5.21)\quad F = \frac{(RSS - URSS)/m}{URSS/(n-k)}$$

where *RSS* is the residual sum of squares from the restricted regression. *URSS* is the *RSS* from the unrestricted regression, *m* is the number of linear restrictions. *k* is the number of parameters (including the intercept) in the unrestricted regression and *n* is the number of observations. The statistic follows the *F* distribution with (*m*, *n-k*) degrees of freedom. If the computed F value from equation (5.21) exceeds the critical F value, the restricted regression is rejected. Using the *RSS* values from Table 5-9, the comprehensive set of F-tests is summarized in Table 5-10.

The tests reveal that four of the eight models (C1, C6, C7 and C8) each outperformed four other models. Only two models (C1 and C8) could be compared to all other models. The most comprehensive model (C1) supports the third degree polynomial specification of output, indicates that fixed costs are identical for each culture style and area, and variable costs are higher for the lantern net style. However, this unrestricted model was rejected when compared to all others.

Comparison of the three remaining models using the adjusted R^2, number of statistically significant variables, and transitivity assumptions on the comparative F-tests (Table 5-10) indicates that model (C6) is the best. Aside from non linear variable costs model (C6) also estimates lower fixed costs but higher variable costs associated with the lantern net culture style. No differences in fixed or variable costs associated with production in different areas (Chuntangin and Kojin) were found.

Table 5-10 Testing Linear Restrictions (Cubic Functions by Production)

Test	F table value (F^*)	Computed F value (F)	Best Model
(C1) versus (C2)	F(1,20) = 5.351	0.032	(C2)
(C1) versus (C3)	F(2,20) = 3.493	2.319	(C3)
(C1) versus (C4)	F(2,20) = 3.493	1.698	(C4)
(C1) versus (C5)	F(3,20) = 3.098	2.642	(C5)
(C1) versus (C6)	F(2,20) = 3.493	0.120	(C6)
(C1) versus (C7)	F(3,20) = 3.098	1.653	(C7)
(C1) versus (C8)	F(4,20) = 2.866	2.519	(C8)
(C2) versus (C3)	F(1,21) = 5.325	5.829	(C2)
(C2) versus (C5)	F(2,21) = 3.467	5.137	(C2)
(C2) versus (C6)	F(1,21) = 5.325	0.218	(C6)
(C2) versus (C7)	F(2,21) = 3.467	2.582	(C7)
(C2) versus (C8)	F(3,21) = 3.072	3.509	(C2)
(C3) versus (C5)	F(1,22) = 5.301	2.934	(C5)
(C3) versus (C7)	F(1,22) = 5.301	0.285	(C7)
(C3) versus (C8)	F(2,22) = 3.443	2.427	(C8)
(C4) versus (C5)	F(1,22) = 5.301	5.259	(C5)
(C4) versus (C8)	F(2,22) = 3.443	3.141	(C8)
(C5) versus (C8)	F(1,23) = 5.279	1.771	(C8)
(C6) versus (C7)	F(1,22) = 5.301	5.129	(C6)
(C6) versus (C8)	F(2,22) = 3.443	5.345	(C6)
(C7) versus (C8)	F(1,23) = 5.279	5.715	(C7)

Using the empirical results, the relationship between total costs and production volume for each culture style is graphed for model (C6) in Figure 5.2. Overall, total costs are higher for the ear suspended style at production volumes below approximately 100 000 kg but are increasingly higher at production levels up to 170 000, which was the highest reported total cost. For the ear suspended style, fixed costs per production cycle for the average farm would be 350.9 million won (although this figure was not statistically significant). For comparison, the difference in fixed costs by culture style were statistically significant and, in particular, fixed costs for the lantern net style were estimated to be 450.4 million won lower.

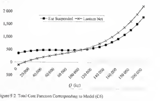

Figure 5.2. Total Cost Function Corresponding to Model (C6)

The variable costs are calculated as the sum of three figures, which depend on the level of production and culture style (any of the specification including ka were rejected

in comparison to C6; see Appendix A for the results of alternative model specifications). The variable cost (VC) equations for each culture style resulting from model (C6) are shown in the following two equations.

(5.22) Ear-suspended $VC = 0.0064Q - 0.000000104Q^2 + 0.000000000000439Q^3$ (C6)

(5.23) Lantern net $VC = 0.0108Q - 0.000000104Q^2 + 0.000000000000439Q^3$ (C6)

Since Q is measured in kg (per farm per rotation), VC will give the total variable cost in million won per kg. Variable costs differ by production style in the magnitude of the coefficient on Q.

Summary and Overview

This chapter contained the model specification, justification, and estimation results associated with the submodels needed for the bioeconomic model, namely a price-weight equation, growth models that link environmental conditions to charn scallop size over time, and a cost equation that estimated fixed and variable costs by culture style (ear-suspended or lantern net). These equations are needed in order to calculate total revenues and costs that are the key components of the objective function in the bioeconomic model (i.e., net present value). The specific models to be used were selected from several alternative specifications using a variety of standard statistical measures and goodness-of-fit tests.

In summary, the selected price model was equation (5.3). Using that model, price is nonlinearly related to charn scallop size and varies seasonally but does not vary by region. Given a scallop of a particular size (cm), equation (5.2) will convert the scallop into weight (kg) and then equation (5.3) will calculate the price of that scallop in won. Separate log-reciprocal growth models will be used for each culture style and region. The

log-reciprocal model is the (G2) model and the empirical results are shown in Tables 5-2 through 5-5. In order to use this model to calculate production, the predicted values need to be transformed to remove the effect of taking the natural logarithm prior to estimation. Specifically, predicted chain scallop size in cm would be $e^{\ln(G)}$ multiplied by the initial size where the exponent of e is the predicted value given levels of the environmental attributes and the estimated coefficients from the G2 equations. The selected cost model (C6) will estimate fixed and variable costs in million won that differ by culture style but not region. The empirical model is presented in Table 5-9. The associated variable cost equations by culture style are shown in equations (5.22) and (5.23). Thus, given the farm-level quantity of production in kg and culture style, model (C6) will calculate total cost in million won.

To complete the bioeconomic model, information is needed on the number of scallops planted on the average farm (i.e., number of hectares, number of lines that can planted in those hectares for each culture style, number of bundles per line for each culture style, and number of scallops per bundle for each culture style). To account for natural mortality over time, a natural mortality rate for each culture style is needed to calculate number of available scallops in each month.

Given the number of scallops available for harvest (number stocked less natural mortality), total revenues will be calculated by multiplying (a) the number of scallops by (b) the weight per scallop (i.e., transformed growth equation used with the weight-size equation) by (c) the price per unit weight for each scallop. The results will be revenue in won that, when divided by one million, will be in units corresponding to the estimated costs (which will be based on the production volume as calculated by multiplying (a) and

(b) above). Since the total cost function estimates the cost per production cycle in million won, net revenue in million won will be obtained by subtracting the total costs from the total revenue. A discount rate is needed to be able to compare the net returns from production horizons that may differ. Lastly, in order to account for stochastic growth, we need to use the means and standard deviations of the environmental variables to calculate expected ubam scallop size. The details of the remaining information will be presented in the next chapter (Chapter 6).

CHAPTER 6
BIOECONOMIC SIMULATION RESULTS

The objective of the model is to maximize the present value of expected net returns to the firm's resources over the planning horizon. The objective function incorporates all submodels derived in the previous chapter namely, a price function, cost function, and clam scallop growth functions that differ by culture style and region. In addition, the following information is needed

- average farm size;
- number of scallop spat planted,
- size of scallops at time of planting
- natural mortality rate,
- variation in environmental conditions; and
- discount rate

The following section describes the assumptions that were made regarding the information needed above and a specification of the objective function. Then, the growth simulations are derived. As a preview these simulations generate 27 scallop sizes for each month based on the probabilities and environmental values associated with each of 27 possible states. Since the probabilities sum to one, these 27 expected sizes can be collapsed into one; this is the essence of the Markovian assumption (i.e., only the last state is relevant). This process is repeated for each beginning month (12 total) and for each culture style (2 total) in each region (2 total). Using the growth simulation results the optimal single rotation is found for each culture style and region by identifying the

maximum discounted expected net returns from the 360 possibilities (i.e., 12 alternative initial months and 30 alternative harvest months). Lastly, a method for evaluating multiple rotations is considered (i.e. implementation of the decision rules from Chapter 3, equation 3.13, to determine the opportunity cost of delaying harvest one period).

Objective and Model Assumptions

The objective of the bioeconomic model is to maximized the expected net present value (*NPV*)

(6.1) $$\text{Expected } NPV_{a,s,i,t} = \left(\frac{1}{1+r}\right)^{t} \left[Y\big|_{a,s,t}\right]$$

where

a = culture areas (a = 1,2 for Chumunjin and Kojin),

s = culture styles (c = 1,2 for lantern net and ear-suspended)

i = initial rotation month (i = 1, 2, ..., 12 for January through December),

t = alternative rotation lengths (t = 2, 3, ..., 31 months), and

r = monthly discount rate (1% or 0.01)

The monthly discount rate is based on the official annual rate of 12 percent set by the International Monetary Fund, which is applicable to South Korea. This rate has recently fallen such that lower rates will also be examined. In addition,

(6.2) $$Y\big|_{a,s,t} = TR\left\{P\left(W(\hat{cm}_{i,a,t}), DS, DW\right), X_{i,a,t}()\right\} - TC\left(\hat{Q}_{i,a,t}(\hat{cm}_{i,a,t}, X_{i,a,t}()), DC\right)$$

where total revenue (*TR*) and total costs (*TC*) are a function of scallop price (*P*), individual weight (*W*), individual size (*cm*), season (*DS*, *DW*), number of surviving scallops (*X*), total production (*Q*) and culture style (DS_i). The ^ indicates the value is predicted from the empirically estimated underlying equations. Note that i is not included

on the right-hand-side; this is because it is related to the stochastic growth and ultimately the expected size of the individual scallops $E[cm_{t,a,s}]$ given the alternative environmental states (27 in total) and probability of each as described in the next section

There are three variables in equation (6.2) that need further definition namely cm, $X()$, and $Q()$. The size of each individual scallop is represented by cm for centimeters, is obtained from the growth equation. Recall that growth G_t is measured as the ratio of the final scallop size to initial size

$$(6.3) \quad G = \frac{cm_{t,s,a}}{cm_{t=0}}$$

where $cm_{t=0}$ is assumed to be 0.34, which is the average size of the scallops at the beginning of the grow-out process (Park, 1998). Using the empirically estimated log-reciprocal growth equations for each culture style and area (i.e., model G2 in Tables 5.2 through 5.5), the following equation can be used to derive an estimate of $cm_{t,s,a}$

$$(6.4) \quad \hat{\ln}\left(\frac{cm_{t,s,a}}{cm_{t=0}}\right) = \hat{\beta}_o + \sum_{j=1}^{4} \hat{\beta}_{j,a,s} \left(\frac{1}{C_{j,a,s}}\right)$$

where C_j represents the four characteristics (explanatory variables) that were used to describe individual scallop growth, namely scallop age (A), water temperature (T), water salinity (S) and the dissolved oxygen content of the water (O). Specifically, the size of the individual scallops at month t using culture style s in area a is found by taking the anti-log of equation (6.4) and multiplying by the initial scallop size

$$(6.5) \quad \hat{cm}_{t,s,a} = cm_{t=0} \, \exp\left[\hat{\beta}_o + \sum_{j=1}^{4} \hat{\beta}_{j,a,s} \left(\frac{1}{C_{j,a,s}}\right)\right]$$

The number of surviving scallops will differ in each time period and by culture style and is calculated as follows

(6.6) $X_{t,s} = X_o \left[(1 - M_{s})^{1/30}\right]^{t}$

where

X_o = number of scallops initially planted (450 000)

M = monthly natural mortality rate (zero to 10 percent)

The estimated number of scallops initially planted was obtained from assumptions on the standard scale of operations (i.e. three plots of 200 m by 200 m each or 12 ha in total from Park (1998) which corresponds to the average culture area size of 12.09 ha from the survey). Each plot can contain 10 production lines and along each line the bundles are spaced at a distance of 1.5 m; this spacing is the same for each culture style. The bundles for the lantern net style typically contain 113 scallops on average and the bundles for the ear suspended style typically contain 56 rows (or cells) with two scallops per row (112 per bundle) (Park, 1998). Multiplying the average number of scallops per bundle (112.5) by the average number of bundles per plot (200 m divided by 1.5 m) times the number of lines per plot (10) times the number of plots per farm (3) equals a total of 450 000 scallops planted per farm for both production styles.

Aside from adverse environmental conditions, predators such as starfish are the major cause of clam scallop natural mortality (this threat will however differ by production style since hanging culture technologies provide a barrier to entry for many predators) (Park, 1998). In terms of the natural mortality rate (M), little empirical work exists for bivalve species, especially by age. Askew (1978) linked oyster mortality to size and computed *monthly* mortality from annual data using the assumption that short-term

rates concur with long-term rates. Following this approach, the cumulative survival rate as reported by Park (1998) was used to derive an estimate of monthly mortality by culture style ($M_{t,s}$). For cham scallops grown out using the ear suspended style, the mortality rate was determined to be 10% from age (month) 1 to age 29. For cham scallops grown out using the lantern net style, mortality was found to be 0% from age 1 to age 10 (due to the effectiveness of barriers) but 10% from age 11 to age 29. Note, the 1/30 power used in the calculation of the survival rate is the adjustment for the number of days per month, which (for simplicity) is assumed to be 30 for each month.

Total production quantities in kg per farm are needed to calculate the total costs of production. This quantity is determined as follows:

(6.7) $Q_{t,e,s} = X_{t,s}(\cdot)\, W(\hat{c}m_{t,e,s})$

Using this information, the total revenue and total costs are calculated as follows:

(6.8) $TR_{t,e} = P[W(\hat{c}m_{e,s})]\; X_{t,s}(X_{s}M_{t,s})$

where the weight and price equations were specified in equations (5.2) and (5.3), respectively, and

(6.9) $TC_{t,e,s} = \eta_{0} + \sum_{k=1}^{2} \hat{\eta}_{k}\; Q_{t,e,s}(\cdot)^{k} + \hat{\eta}_{3}\; DC_{s} + \hat{\eta}_{4}\; Q_{t,e}(\cdot)\; DC_{s}$

where the parameter values are from model (C6) in Table 5.9.

Growth Simulations

Cham scallop growth was simulated using equation (6.4) with the mean and the extreme values for each environmental attribute (i.e., water temperature, salinity, and dissolved oxygen). The extreme values were calculated by adding or subtracting two standard deviations from the mean (Holmsn, 1993). Thus, there are three possible levels

of each environmental attribute in each month and for each region. These values are shown in Tables 6-1 and 6-2 for Kojin and Chumunjin respectively

Using the standard deviations exposure to a mean value had a 68 percent probability and exposure to each of the extreme values had a 16 percent probability (Holman, 1993) That is the scallops have different probabilities of being exposed to different levels of each environmental attribute (i.e., the mean or extreme values) which will affect ultimate scallop size Using each combination of mean over mean and under mean values, 27 possible environmental states (E) for each culture style in each region were calculated

Table 6-3 shows the resulting environmental states and probabilities used for each culture style and region. For example the probability of having environment state E1 (that consists of the mean levels of temperature, dissolved oxygen, and salinity in a given month) is 0 3144 (multiply 0 68 the probability of a mean value by 0 68 and 0 68) or 31 44 percent. Using the Kojin environmental values the levels of characteristics associated with state E1 in the month of August would be T = 0 0555 O = 0 1671 and S = 0 0303 (Table 6-1) The probability of E2 consisting of the mean temperature and dissolved oxygen but over mean salinity in a given month is 0 0739 (0.68 multiplied by 0 68 and 0 16) or 7 39 percent Similarly the probability of having E3 consisting of mean temperature and dissolved oxygen but under mean salinity in a given month is also 0 0739 (0 68 multiplied by 0 68 and 0 16) or 7 39 percent, and so on

The probability of exposure to a given environmental state is assumed to be constant over time (i.e., independent of scallop age) However actual values for a given environmental state and their impact on growth vary by month due to the age (A) effect.

Table 6-1 Monthly Mean and Extreme Environmental Values for Kojin

Month	Attribute	Mean	Over Mean	Below Mean
August	Temperature	0.0555	0.0598	0.0512
	Dissolved Oxygen	0.1671	0.1833	0.1509
	Salinity	0.0303	0.0317	0.0289
September	Temperature	0.0566	0.0618	0.0514
	Dissolved Oxygen	0.1718	0.1852	0.1584
	Salinity	0.0304	0.0317	0.0291
October	Temperature	0.0607	0.0626	0.0589
	Dissolved Oxygen	0.1706	0.1963	0.1450
	Salinity	0.0303	0.0313	0.0293
November	Temperature	0.0726	0.0736	0.0715
	Dissolved Oxygen	0.1706	0.2021	0.1391
	Salinity	0.0300	0.0310	0.0290
December	Temperature	0.1063	0.1105	0.1021
	Dissolved Oxygen	0.1594	0.1736	0.1451
	Salinity	0.0297	0.0303	0.0291
January	Temperature	0.1457	0.1739	0.1176
	Dissolved Oxygen	0.1545	0.1674	0.1416
	Salinity	0.0294	0.0297	0.0292
February	Temperature	0.1469	0.1860	0.1079
	Dissolved Oxygen	0.1502	0.1633	0.1371
	Salinity	0.0295	0.0302	0.0288
March	Temperature	0.1377	0.1695	0.1059
	Dissolved Oxygen	0.1532	0.1662	0.1402
	Salinity	0.0293	0.0297	0.0290
April	Temperature	0.0961	0.1317	0.0604
	Dissolved Oxygen	0.1745	0.2047	0.1444
	Salinity	0.0294	0.0297	0.0291
May	Temperature	0.0919	0.1178	0.0660
	Dissolved Oxygen	0.1599	0.1616	0.1583
	Salinity	0.0296	0.0301	0.0291
June	Temperature	0.0851	0.1239	0.0464
	Dissolved Oxygen	0.1610	0.1668	0.1551
	Salinity	0.0299	0.0300	0.0297
July	Temperature	0.0721	0.0903	0.0540
	Dissolved Oxygen	0.1661	0.1753	0.1569
	Salinity	0.0301	0.0303	0.0299

Table 6-2 Monthly Mean and Extreme Environmental Values for Chamanjun

Month	Attribute	Mean	Over Mean	Below Mean
August	Temperature	0.0515	0.0582	0.0447
	Dissolved Oxygen	0.1929	0.2470	0.1389
	Salinity	0.0302	0.0313	0.0290
September	Temperature	0.0506	0.0579	0.0433
	Dissolved Oxygen	0.1864	0.2040	0.1687
	Salinity	0.0305	0.0315	0.0296
October	Temperature	0.0550	0.0603	0.0497
	Dissolved Oxygen	0.1697	0.1930	0.1464
	Salinity	0.0303	0.0309	0.0296
November	Temperature	0.0673	0.0738	0.0608
	Dissolved Oxygen	0.1657	0.1901	0.1414
	Salinity	0.0300	0.0306	0.0293
December	Temperature	0.0923	0.1095	0.0751
	Dissolved Oxygen	0.1599	0.1736	0.1461
	Salinity	0.0297	0.0302	0.0293
January	Temperature	0.1209	0.1494	0.0924
	Dissolved Oxygen	0.1468	0.1692	0.1244
	Salinity	0.0294	0.0298	0.0291
February	Temperature	0.1400	0.2051	0.0750
	Dissolved Oxygen	0.1410	0.1748	0.1073
	Salinity	0.0293	0.0297	0.0289
March	Temperature	0.1382	0.1836	0.0929
	Dissolved Oxygen	0.1465	0.1660	0.1270
	Salinity	0.0293	0.0296	0.0290
April	Temperature	0.1105	0.1555	0.0654
	Dissolved Oxygen	0.1564	0.1838	0.1290
	Salinity	0.0294	0.0296	0.0291
May	Temperature	0.0839	0.1047	0.0631
	Dissolved Oxygen	0.1613	0.1774	0.1452
	Salinity	0.0296	0.0301	0.0291
June	Temperature	0.0811	0.1252	0.0371
	Dissolved Oxygen	0.1664	0.1909	0.1419
	Salinity	0.0297	0.0303	0.0290
July	Temperature	0.0600	0.0723	0.0476
	Dissolved Oxygen	0.1761	0.2043	0.1480
	Salinity	0.0300	0.0304	0.0297

Table 6-3 Alternative Environmental States used in the Growth Simulations

State	Temperature	Dissolved Oxygen	Salinity	Probability
E1	*	*	*	0.3144
E2	*	*	+	0.0739
E3	*	*	[illegible]	0.0739
E4	*	+	*	0.0739
E5	*	+	+	0.0174
E6	*	+	[illegible]	0.0174
E7	*	[illegible]	*	0.0739
E8	*	[illegible]	+	0.0174
E9	*	[illegible]	-	0.0174
E10	+	*	*	0.0739
E11	+	*	+	0.0174
E12	+	*	-	0.0174
E13	+	+	*	0.0174
E14	+	+	+	0.0040
E15	+	+	–	0.0040
E16	+	–	*	0.0174
E17	+	-	+	0.0040
E18	+	-	-	0.0040
E19	-	*	*	0.0739
E20	–	*	+	0.0174
E21		*	-	0.0174
E22		+	*	0.0174
E23		+	+	0.0040
E24		+	-	0.0040
E25	-		*	0.0174
E26	[illegible]		+	0.0040
E27	-	-	–	0.0040

Note * is mean + is over mean, and – is under mean

Chum scallop growth simulations are conducted for each culture style (s), region (a), planting month (i), and environmental state ($k = 1, 2, \ldots 27$). The simulations begin with spat of a given initial size ($cm_{t=0} = 0.34$ cm) and planting month (i). The 27 possible environmental states in period 1 (and resulting scallop sizes) are then exposed to each of the possible 27 environmental states in period 2. The output of growth determined by exposure to E1 in period 2 is calculated as the average size of the 27 scallops in period 1 transitioning through E1 and into period 2. Thus, the output of each sequential growth period is 27 new scallop sizes. Each new scallop size means an average of 27 potentially different scallops sizes transitioning through a given period. Thus, scallop size at each month will differ due to different environment conditions in the initial month (in addition to differences by culture type and region) even though the process began equal sized scallops (i.e., 0.34 cm).

Examples of the growth simulations by culture style and region assuming the process began in August with 0.34 cm scallops are presented in tables 6-4 through 6-7. Growth simulations cover 30 months in total and are calculated using a 27×30 matrix of final scallop sizes for each period. Each cell in the matrix shows the size of the scallop at a given month and for a given environment. This process is repeated with each of the 12 calendar months as the initial growth period (i).

Final monthly expected scallop sizes are calculated by the outcomes of the growth simulation and the environmental probabilities (Table 6-3). The expected size of a scallop at month t is the same as the sum of the size of a scallop exposed to environment k in period t times the probability of encountering environment k. Eventually each 27×30 matrix of final scallop sizes is reduced to a 1×27 vector of final sizes.

Table 6-4 Expected Chant Scallop Size for Ear-suspended Style in Chumunjin from Planting a 0.34 cm Scallop in August

Option	Period 1	Period 2	Period 14	Period 15	Period 16	...	Period 29	Period 30
E1	0.769	1.293	9.114	9.601	10.088		13.433	13.517
E2	0.753	1.270	8.954	9.483	9.971		13.277	13.401
E3	0.785	1.316	9.276	9.728	10.206		13.591	13.633
E4	0.776	1.296	9.140	9.639	10.129		13.488	13.548
E5	0.760	1.274	8.980	9.520	10.011		13.331	13.431
E6	0.792	1.320	9.303	9.758	10.248		13.646	13.665
E7	0.762	1.289	9.087	9.564	10.047		13.378	13.486
E8	0.746	1.266	8.928	9.447	9.930		13.223	13.370
E9	0.778	1.312	9.249	9.683	10.165		13.535	13.602
E10	0.768	1.292	9.107	9.596	10.081		13.424	13.492
E11	0.752	1.269	8.947	9.478	9.964		13.268	13.377
E12	0.785	1.315	9.269	9.715	10.199		13.581	13.609
E13	0.775	1.295	9.133	9.633	10.122		13.478	13.523
E14	0.759	1.273	8.974	9.515	10.005		13.322	13.407
E15	0.792	1.319	9.296	9.753	10.241		13.637	13.640
E16	0.761	1.288	9.080	9.559	10.040		13.369	13.461
E17	0.745	1.265	8.921	9.442	9.924		13.214	13.346
E18	0.778	1.311	9.242	9.677	10.158		13.526	13.578
E19	0.769	1.294	9.120	9.626	10.095		13.442	13.541
E20	0.753	1.271	8.961	9.489	9.977		13.286	13.425
E21	0.786	1.317	9.283	9.726	10.213		13.680	13.658
E22	0.776	1.297	9.147	9.644	10.136		13.497	13.572
E23	0.760	1.275	8.987	9.526	10.018		13.340	13.456
E24	0.793	1.321	9.310	9.764	10.255		13.655	13.689
E25	0.762	1.290	9.094	9.569	10.054		13.387	13.510
E26	0.747	1.267	8.934	9.452	9.937		13.232	13.394
E27	0.779	1.313	9.256	9.688	10.172		13.545	13.545

Table 6.5. Expected Clam Scallop Size for Lantern Net Style in Chumungun from Planting a 0.34 cm Scallop in August

Option	Period 1	Period 2	Period 14	Period 15	Period 16	Period 29	Period 30
E1	0.771	1.302	9.179	9.698	10.204	13.573	13.606
E2	0.758	1.283	9.049	9.602	10.108	13.479	13.531
E3	0.784	1.320	9.311	9.795	10.300	13.667	13.680
E4	0.773	1.303	9.187	9.709	10.216	13.582	13.621
E5	0.760	1.284	9.057	9.613	10.120	13.488	13.546
E6	0.786	1.322	9.319	9.806	10.312	13.677	13.695
E7	0.769	1.301	9.171	9.687	10.191	13.563	13.590
E8	0.756	1.282	9.041	9.591	10.096	13.469	13.516
E9	0.782	1.319	9.303	9.784	10.288	13.658	13.665
E10	0.770	1.300	9.168	9.689	10.192	13.533	13.539
E11	0.757	1.282	9.036	9.593	10.097	13.439	13.665
E12	0.783	1.319	9.299	9.786	10.289	13.627	13.613
E13	0.772	1.301	9.176	9.700	10.204	13.542	13.554
E14	0.759	1.283	9.046	9.604	10.109	13.448	13.460
E15	0.786	1.320	9.308	9.797	10.301	13.636	13.628
E16	0.768	1.299	9.160	9.678	10.180	13.523	13.524
E17	0.755	1.281	9.030	9.582	10.085	13.430	13.451
E18	0.781	1.318	9.291	9.775	10.276	13.618	13.598
E19	0.772	1.303	9.191	9.707	10.215	13.613	13.672
E20	0.759	1.285	9.061	9.611	10.119	13.518	13.598
E21	0.785	1.322	9.323	9.804	10.312	13.708	13.747
E22	0.774	1.304	9.199	9.718	10.227	13.622	13.687
E23	0.761	1.286	9.068	9.622	10.131	13.528	13.613
E24	0.787	1.323	9.331	9.815	10.324	13.717	13.762
E25	0.770	1.302	9.183	9.696	10.203	13.603	13.637
E26	0.757	1.284	9.053	9.600	10.107	13.509	13.583
E27	0.783	1.321	9.315	9.793	10.299	13.698	13.732

Table 6 6 Expected Cham Scallop Size Ear-suspended Style in Kojin from Planting a 0 34 cm Scallop in August

Option	Period 1	Period 2	Period 14	Period 15	Period 16	Period 29	Period 30
E1	0 775	1.312	9 379	9 977	10.535	14.493	14.296
E2	0 740	1.257	8 993	9 666	10 183	14 213	14 172
E3	0 812	1 370	9 790	10.297	10 999	14 778	14 421
E4	0 757	1 296	9 195	9 608	10 059	14 193	14 028
E5	0 722	1.232	8 808	9 309	9 723	13 920	13 906
E6	0 793	1 343	9 600	9 917	10 406	14 473	14 151
E7	0 794	1 339	9.565	10.359	11 933	14 798	14.569
E9	0 757	1.282	9 162	10 037	10 665	14.513	14 442
E9	0 932	1.397	9 985	10 692	11.415	15 090	14 697
E10	0 772	1.306	9 335	9 960	10.525	14 439	13 945
E11	0 737	1.251	9 942	9 650	10 173	14 161	13 823
E12	0 809	1.363	9 746	10 290	10 889	14 724	14 067
E13	0.754	1.280	9 153	9 592	10 049	14 141	13 693
E14	0 719	1.227	8 767	9.294	9 714	13 868	13 564
E15	0 790	1 337	9.555	9 990	10 396	14 420	13 804
E16	0 791	1 332	9.521	10.342	11 023	14 744	14 211
E17	0 755	1 276	9 120	10 020	10.655	14 459	14 087
E19	0 929	1.391	9 939	10 674	11 404	15 934	14 335
E19	0 778	1.319	9 421	9 993	10 545	14 546	14.656
E20	0 742	1.263	9 024	9 692	10 192	14.266	14.529
E21	0 915	1 376	9 836	10.314	10 909	14 833	14 795
E22	0 760	1.292	9 238	9 624	10 388	14 246	14.382
E23	0 725	1 239	9 848	9 324	9 732	13 971	14.257
E24	0 796	1.349	9 644	9 933	10 416	14 526	14 508
E25	0 797	1.344	9 609	10 377	11 044	14 853	14 936
E26	0 760	1 299	9.204	10 054	10 675	14 566	14 806
E27	0 835	1 403	10 031	10 710	11 425	15 145	15.067

Table 6.7. Expected Cham Scallop Size for Lantern Net Style in Kojin from Planting a 0.34 cm Scallop in August

Option	Period 1	Period 2	Period 14	Period 15	Period 16	...	Period 29	Period 30
E1	0.783	1.332	9.617	10.214	10.768		14.578	14.361
E2	0.745	1.273	9.185	9.875	10.385		14.278	14.228
E3	0.823	1.395	10.069	10.564	11.165		14.884	14.496
E4	0.763	1.304	9.409	9.795	10.229		14.244	14.063
E5	0.726	1.245	8.987	9.470	9.865		13.951	13.933
E6	0.802	1.365	9.851	10.132	10.606		14.543	14.195
E7	0.804	1.362	9.830	10.650	11.335		14.920	14.666
E8	0.765	1.301	9.388	10.296	10.932		14.613	14.530
E9	0.845	1.426	10.292	11.015	11.754		15.233	14.803
E10	0.780	1.326	9.571	10.196	10.757		14.522	13.993
E11	0.742	1.266	9.141	9.856	10.374		14.223	13.863
E12	0.820	1.388	10.021	10.546	11.154		14.827	14.124
E13	0.760	1.297	9.364	9.778	10.219		14.189	13.702
E14	0.723	1.239	8.943	9.454	9.855		13.897	13.575
E15	0.798	1.358	9.804	10.114	10.596		14.488	13.830
E16	0.801	1.355	9.783	10.631	11.324		14.862	14.290
E17	0.762	1.294	9.343	10.279	10.921		14.556	14.157
E18	0.842	1.419	10.242	10.996	11.742		15.175	14.423
E19	0.786	1.339	9.663	10.231	10.778		14.634	14.740
E20	0.748	1.279	9.230	9.892	10.395		14.333	14.603
E21	0.826	1.402	10.118	10.583	11.176		14.942	14.878
E22	0.766	1.310	9.454	9.812	10.239		14.299	14.434
E23	0.728	1.251	9.030	9.487	9.874		14.005	14.308
E24	0.805	1.371	9.899	10.149	10.617		14.600	14.569
E25	0.807	1.368	9.877	10.668	11.346		14.977	15.052
E26	0.768	1.307	9.434	10.314	10.942		14.669	14.913
E27	0.848	1.433	10.341	11.034	11.765		15.292	15.193

For comparison, the range of scallop sizes that would be expected in month 30 given the 27 possible environmental states in each period are summarized for each culture style (lantern net, ear suspended) region (Chumunjin, Kojin), and initial planting month (i) in Table 6-8. The extreme values (12.751 cm and 16.345 cm) were both associated with lantern net production in Kojin indicating greater variability associated with that type of operation and region. In general the values are relatively high given the average market size of scallops (i.e., 10 cm to 12 cm), however, these values are associated with a 30-month grow-out, which is at least 6 months longer than typical (Park, 1998). A 30 period horizon was used in order to compare the expected discounted net benefits of harvesting early or delaying harvest past the traditional harvest period.

Optimal Single Rotation

The optimal harvesting plan for each culture style in each region is determined by comparing the expected net present values ($E[NPV]$) associated with each alternative (equation 6.1). In practice this is accomplished in two stages for each culture style in each region. In stage one the highest $E[NPV]$ is identified among the 27 possibilities that result from all possible stochastic growth simulations given an initial planting month. In the second stage, the highest expected net present values associated with each initial planting month (i) are compared. The information to make the second stage decisions are summarized in Tables 6-9 through 6-12. Once the maximum $E[NPV]$ is identified for each culture style and region, the associated harvest month (t) and initial month (i) reveal the optimal rotation length. The resulting optimal scallop size and weight are also indicated.

Table 6-8 Summary of Expected Cham Scallop Sizes (cm) in period 30 by Beginning Grow-out Month for Each Region and Culture Style

		Region	
Style	Month	Chumunjin	Kojin
Lantern Net	January	13.514 to 13.903	12.751 to 14.271
	February	13.571 to 13.817	12.804 to 14.330
	March	13.487 to 14.052	13.739 to 16.130
	April	13.538 to 13.989	14.027 to 16.142
	May	13.531 to 13.860	14.004 to 16.345
	June	13.528 to 13.849	14.190 to 16.013
	July	13.500 to 13.780	14.055 to 15.466
	August	13.465 to 14.762	13.575 to 15.193
	September	13.276 to 13.763	13.620 to 14.988
	October	13.390 to 13.714	13.535 to 14.836
	November	13.405 to 13.762	13.303 to 14.638
	December	13.458 to 13.767	13.107 to 14.422
Ear suspended	January	13.569 to 14.124	12.761 to 13.936
	February	13.668 to 14.021	13.828 to 14.831
	March	13.463 to 14.318	13.706 to 15.901
	April	13.516 to 14.096	13.947 to 15.957
	May	13.451 to 13.910	14.029 to 16.140
	June	13.403 to 13.840	13.695 to 16.108
	July	13.430 to 13.751	14.050 to 15.344
	August	13.401 to 13.689	13.564 to 15.067
	September	13.272 to 13.810	13.571 to 14.820
	October	13.445 to 13.803	13.398 to 14.632
	November	13.546 to 13.939	13.285 to 14.402
	December	13.611 to 13.984	12.965 to 14.159

Note The final sizes are higher than the observed market sizes since they correspond to the size in period 30 which is longer than is usually observed and likely longer than the optimal rotation (i.e., the final sizes in earlier periods will be smaller)

Examining the results in table 6-9, the maximum expected *NPV* (i.e. 133,504,000 won) for production in Chumunjin using the ear-suspended style is associated with planting spat in March and harvesting two years (24 months) later in March. At that time the market size would average 12.95 cm (i.e., 290.7 grams) per scallop.

Table 6-9 Optimal Harvesting for the Ear-suspended Style in Chumunjin

Planting Month	Grow-out Months	Harvest Month	Scallop Weight (g)	Scallop Size (cm)	E[*NPV*] (thous won)
August	24	August	290.69	12.95	118.840
September	26	November	311.32	13.18	124.977
October	25	November	303.09	13.09	128.177
November	24	November	290.73	12.95	129.109
December	25	January	308.63	13.15	132,090
January	24	January	290.70	12.95	133.499
February	24	February	290.69	12.95	133,498
March	24	March	290.72	12.95	133.504
April	24	April	290.69	12.95	129.098
May	24	May	290.69	12.95	129,099
June	23	May	268.02	12.68	120.078
July	24	July	290.73	12.95	118.850

For farmers using lantern nets to grow-out cham scallops in Chumunjin, Table 6-10 indicates that planting spat in May will maximize expected net present value (*NPV*) if scallops are allowed to grow for just 20 months and are harvested in January. At that time, E[*NPV*] would equal approximately 114 million won from the harvest of cham scallops averaging 11.93 cm and weighing 212.95 grams. Overall, the ear suspended style in Chumunjin is associated with longer optimal grow-out periods and higher E[*NPV*] values as compared to the use of lantern nets.

Table 6-10 Optimal Harvesting for Lantern Net Style in Chumunjin

Planting Month	Grow-out Months	Harvest Month	Scallop Weight (g)	Scallop Size (cm)	E[*NPV*] (thous won)
August	21	May	223.60	12.09	108,660
September	20	May	201.43	11.74	105,987
October	19	May	183.15	11.43	99,579
November	20	July	209.51	11.87	97,485
December	21	September	233.40	12.23	97,648
January	22	November	250.17	12.46	102,700
February	21	November	230.44	12.19	108,698
March	20	November	211.72	11.91	109,019
April	21	January	236.59	12.27	112,729
May	20	January	212.95	11.93	114,003
June	21	March	228.12	12.15	113,413
July	20	March	204.66	11.80	111,801

In the case of growing out clam scallops in the Kojin region using ear suspended nets E[*NPV*] was maximized at 142.8 million won from planting spat in April and harvesting 21 months later in January at an average size of 13.04 cm or 298.31 grams (Table 6-11). For comparison, use of the lantern net style in Kojin resulted in the maximum expected returns equaling just 116.976 million won (Table 6-12). The optimal planting month with the lantern net style was July and the optimal farming period (rotation length or duration of grow-out) was just 19 months. Under such a rotation harvest would occur in February and consist of scallops averaging 12.0 cm or 217.44 grams.

Table 6-11. Optimal Harvesting for Ear-suspended Style in Kojin

Planting Month	Grow-out Months	Harvest Month	Scallop Weight (g)	Scallop Size (cm)	E[NPV] (thous won)
August	23	July	294.67	12.99	122,214
September	23	August	286.52	12.90	120,078
October	23	September	300.00	13.05	122,747
November	23	October	298.73	13.04	122,684
December	23	November	300.11	13.05	133,149
January	23	December	304.72	13.10	133,026
February	22	December	301.70	13.07	135,702
March	21	December	291.47	12.96	137,366
April	21	January	298.31	13.04	142,841
May	22	March	290.58	12.95	138,953
June	23	May	286.30	12.90	130,396
July	23	June	290.45	12.95	121,305

Table 6-12. Optimal Harvesting for Lantern Net Style in Kojin

Planting Month	Grow-out Months	Harvesting Month	Scallop Weight (g)	Scallop Size (cm)	E[NPV] (thous won)
August	19	March	200.66	11.73	112,601
September	20	May	205.45	11.81	107,333
October	19	May	182.78	11.42	99,371
November	20	July	222.48	12.07	99,633
December	20	August	226.19	12.12	99,785
January	20	September	239.15	12.31	98,525
February	19	September	228.85	12.16	101,615
March	18	September	213.01	11.93	102,218
April	19	November	253.26	12.50	106,310
May	18	November	225.90	12.12	114,907
June	19	January	243.71	12.37	114,992
July	19	February	237.44	12.00	116,976

Comparing the optimal results from tables 6-9 through 6-12, maximum expected *NPV* E[*NPV*] ranged from 114.0 million won to 142.8 million won per "crop." Neither production style or region produced consistently higher E[*NPV*] values. In addition, optimal planting months, rotation lengths and harvest weights varied by style and region. One notable commonality, however is that the optimal harvest months (i.e., January through March) are generally associated with the months when price is highest. Also, the expected NPV is relatively robust for the ear suspended style in Chumunjin, which suggests that alternative production schedules have smaller opportunity costs and perhaps less risk.

Decisions Regarding Multiple Rotations

A continuous or multiple rotation analysis would consider the comparison of maximum expected NPV over a repeating pattern of sequential planting, grow-out, and harvest periods. A given optimal production schedule such as those identified in Tables 6-9 through 6-12 would dictate the earliest time in which the second production cycle could begin. The optimal long-run rotation could be identified through connecting consecutive production cycles and comparing the resulting discounted expected returns. For example, an initial March planting with grow-out for 24 months using the ear suspended style in Chumunjin (Table 6-9) would be harvested in March of the third year in order to maximize E[NPV]. This rotation allows for replanting in April of the third year. Simultaneous harvest and replant (i.e., in the same month) are impossible because of the time and labor requirements. Therefore, the effective minimum rotation time is the optimal grow-out time plus one month. For example, if planting begins in July in Kojin and the optimal farming period is 19 months when using lantern nets (Table 6-12) then

harvest would occur in February of the second year such that replanting could occur as early as March in the second year.

A delayed cycle would include varying durations of "down months". A down month is one in which the culture operation is not running (i.e., no spats are planted, no scallops are in grow-out and none are being harvested). A down month is optimal when the expected net present value of the subsequent rotation would be increased by waiting to plant until a more lucrative cycle begins. Alternatively, the harvest of the existing stock of scallops could be delayed past the optimal. The determination of whether such a delay is optimal can be based on a comparison of the reduced expected net present value of the delayed harvest with the expected net present value of the next optimal rotation.

Using the optimal single rotation results *NPVs* were calculated for the optimal single rotation followed by various durations of down time. This process was continued until a repeatable pattern was found. Thus, the discounted net revenue potential of all combinations of immediate replacement and delayed cycles was calculated. Calculations of the *NPV* of all scenarios are used to identify the decision of the optimal rotation pattern.

The optimal single rotation schedules for each grow-out style and region are summarized in the first three rows of Table 6.13. In addition, the month in which the second rotation begins and the timing of the subsequent grow-out and harvest are also included. This information is reported for each cycle until the optimal repeatable pattern is found (i.e., four rotation cycles for each style-region combination in order to compute expected *NPV* values). Note that the results indicate a longer waiting period for the ear-suspended style in Chumangin. One partial explanation for this is the relatively low

intercept associated with the growth model (G2, Table 5-2) and higher costs for the ear-suspended style at total production volumes below approximately 110,000 kg (Fig. 5-2).

Table 6-13. Continuous Planting Rotations by Culture Style and Region

	Chunnampu		Kojin	
	Ear-suspended	Lantern Net	Ear-suspended	Lantern Net
Planting Month	March	May	April	July
Growing Periods	24	20	21	19
Harvest Month	March	January	January	February
Waiting Periods	6	2	2	2
Planting Month	October	April	April repeat	May
Growing Periods	25	21		18
Harvest Month	November	January		November
Waiting Periods	No	2		5
Planting Month	December	April repeat		May repeat
Growing Periods	25			
Harvest Month	January			
Waiting Periods	No			
Planting Month	February			
Growing Periods	24			
Harvest Month	February			
Waiting Periods	No			
Planting Month	March repeat			

Note: Waiting periods indicate the number of months that harvest is delayed (and *NPV* falls).

As an example of how the conclusions in Table 6-13 were reached, the planting rotations and associated returns for the lantern net style in Kojin are described in Table 6-14. This type of operation was selected since the lantern net style was the primary culture method in 1996 and the single rotation optimal harvest pattern produced higher expected *NPV*s in the Kojin region.

Table 6-14 Optimal Continuous Planting Rotations for the Lantern Net Style in Kojin

Immediate Replacement				Delayed Replacement			
Plant	Grow-out	Harvest	*NPV* (million won)	Plant	Grow-out	Harvest	*NPV* (million won)
First rotation cycle.				First rotation cycle			
Jul	19	Feb	116.98	Jul	19	Feb	116.98
Mar	18	Sep	102.22	Wait 1 month			115.82
Apr	19	Nov	106.31	Wait 2 months			114.67
May	18	Nov	114.91	Wait 3 months			113.54
Second rotation cycle:				Second rotation cycle			
May	18	Nov	114.91	May	18	Nov	114.91
Dec	20	Aug	99.79	Wait 1 month			113.77
Jan	20	Sep	98.53	Wait 2 months			112.64
Feb	19	Sep	101.62	Wait 3 months			111.53
Mar	18	Sep	102.22	Wait 4 months			110.42
Apr	19	Nov	106.31	Wait 5 months			109.33
May	18	Nov	114.91	Wait 6 months			108.25

May repeat

The analysis begins with the optimal rotation pattern identified in Table 6-12 which would begin with planting in July and harvest 19 months later (in the third year) in February for an E[*NPV*] of 116.98 million won. If a farmer decided to replant immediately (i.e., a March initial planting scenario) the expected net present value of returns would equal 102.2 million won (Table 6-12). Alternatively, by waiting one month (i.e., delaying harvest one month and replanting in April) returns would equal 115.8 million won from the first rotation (i.e., *NPV* falls just over one million won from delaying harvest, primarily due to discounting). By immediately replanting in April

expected *NPV* would total 106.31 million won (Table 6-12). In contrast, by waiting two months to harvest, expected *NPV* would total 114.67 million won (another 1.2 million won decline from delaying harvest past the optimal rotation length). However, if he waits three months (not planting until June), *NPV* would fall to 113.54 million won, which is lower than the *NPV* associated with an initial May planting scenario of 114.91 million won (Table 6-12). That is, a farmer who wants to maximize profit has to begin an optimal rotation cycle when the NPV of beginning a new rotation is greater than the NPV associated with delaying harvest of the current rotation.

In the case of the second rotation cycle, the analysis is repeated beginning with a rotation cycle that begins in May. The optimal rotation length is 18 months, which would suggest harvest in November for maximum discounted returns of 114.91 million won. However, an immediate replacement (beginning grow-out in December) would produce and NPV of just 59.79 million won. Using the approach outlined above, an E[NPV]-maximizing farmer should delay harvest months until April such that the subsequent initial planting could occur in May for a return of 114.91. At this point a repeating pattern has emerged with planting in May and harvesting in November, 18 months later.

Note that this decision process pertained to a farmer in the optimal harvest period. That is, given that the optimal month to harvest has been reached, what should the farmer do given his/her knowledge of the optimal single rotations derived from this study? The only choices at this point are to harvest and replace or delay harvest and replace later. This is a very different problem than deciding how to optimize over a longer run horizon.

Summary

The determination of an optimal rotation schedule involved the identification of the (expected) *NPV*-maximizing initial planting date (month), duration of grow-out (total

number of months), and harvest period. The optimal rotation schedule varied by production style (lantern net and ear-suspended) and region (Chuuk and Kojin) due to differences in (1) growth rates from variable environmental conditions, (2) weight and season-dependent prices and (3) costs that varied by production volume and culture method.

The variation in optimal returns (expected *NPV*) associated with alternative initial grow-out periods for each culture style and region suggests differences in the opportunity costs of deciding when to harvest; a wider variation in *NPV*'s could indicate that type of operation is faced with greater risk.

Since the optimal rotation schedule involves an initial starting month and specific grow-out period there are implications for the optimal rotations when multiple rotations are considered (unless the optimal rotation length was 23 months). This is because the discounted *NPV* from delaying harvest needs to be compared with the net returns from beginning a new rotation. The process for conducting such comparisons was outlined using an example for lantern net culture in Kojin. Recall, however, that this process was based on the farmer being at the optimal harvest month. A similar analysis could have been conducted for examining harvests earlier than optimal. Alternatively, a successive rotation study could be conducted.

The following final chapter will summarize this study and elaborate on the appropriate use and comparison of the empirical results. Given there are several underlying assumptions, an appropriate interpretation of the results and use of the approach is warranted.

CHAPTER 7
SUMMARY, CONCLUSIONS AND FUTURE RESEARCH

Summary

Aquaculture in Korea is increasingly considered a means of augmenting the domestic supply of fresh seafood in order to satisfy the continually increasing demand. In response, the aquaculture of cham scallops (*Patinopecten yessoensis*) in particular, which is a relatively high-valued species, has experienced rapid growth in production since 1990. The major producing regions are Chumunjin and Kojin. Each region has different environmental and economic characteristics that are important to the success of the cham scallop industry in Korea. In addition, two alternative culture styles can be used (i.e., lantern net or ear-suspended) which are characterized by different growth and mortality rates. Demand is strong year-round (which supports a continuous supply to the market), but seasonal, regional, and technological variations can complicate the determination of optimal harvesting plans. Such optimal plans are important to resource managers attempting to allocate revenue-generating licenses by culture method and geographic region but are also important to individual investors or community cooperatives.

The primary modeling objective of this study was to specify and estimate a bioeconomic model of an average cham scallop grow-out operation in Korea (Kangwon province) that can be used to evaluate and improve management decisions. The methodology used was based on that developed by Holman (1993) for hard clams but is

unique in the number of dimensions considered, namely multiple geographic regions and culture styles

The development of the bioeconomic model relied on several distinct submodels. On the economic side a seasonal price weight relationship (at the wholesale level) was estimated in order to account for the added benefit of allowing additional growth by delaying harvest and to capture seasonal demand effects. Using standard goodness-of-fit tests, the best form of the price model was a polynomial of second order. In terms of costs, total costs from an industry survey were used to estimate fixed and variable costs based on production levels and culture style (results from alternative cost specifications were shown in the Appendix). The linear and polynomial cost functions were found to have the best fit. On the biological side, growth was specified of as a function of scallop age, water temperature, salinity, and dissolved oxygen. Following recent literature several functional forms were hypothesized and estimated for the growth relationships. The log reciprocal growth model performed the best. Overall, the empirical submodels were very promising in that they were able to explain a relatively high degree of the observed variation in clam scallop prices, production costs, and clam scallop growth in the late 1990s.

To account for stochastic growth, simulations were conducted using the probabilities of 27 alternative environmental states that were calculated from three possible levels (at mean, below mean or above mean) of the three environmental attributes (water temperature salinity and dissolved oxygen). Since the levels of the environmental values varied by month and region and the growth equations were specific to each culture style, predicted growth differs in each scenario (48 in total)

beginning in period 1 (i.e., month 1). For each time period and scenario the probabilities are multiplied by the predicted growth (i.e., scallop size from the estimated equation for that time period, culture style and region) in order to arrive at an estimate of expected scallop size that is carried over into the next period. This process is repeated for each of the 30 periods for each scenario.

The monthly probabilistic growth figures for each scenario were then multiplied by the number of surviving scallops in each period (based on a stocking density of 450 000 scallops, a 12 ha farm and natural mortality rates that differed by culture style), scallop weight and the weight-dependent price equations to estimate expected net revenues. By subtracting the estimated fixed and variable costs, the optimal harvest times and rotations (i.e., initial planting month and duration of grow-out) were identified. The optimal harvest plan was the one that maximized the expected net present value (*NPV*) and optimal plans were identified for each culture style and region.

Overall, the maximum expected *NPV* for each alternative type of operation (culture style, region, and initial planting month scenario) differed by as much as 26 percent. The optimal (expected *NPV*-maximizing) grow-out period ranged from March to July and the optimal duration of grow-out ranged from 19 to 24 months depending on the region and culture style. Thus, there could be potential gains from altering both the private and public management of the sham scallop resource. Private managers (farm operators or license holders) may be able to increase economic returns by delaying harvest in order to market larger, more valuable scallops. For example, the primary market size of sham scallops currently ranges from 10 to 12 cm, but the optimal market

size from this bioeconomic study ranged from 11 43 to 13 18 cm (depending on region, culture style, and initial planting month).

Resource managers on behalf of the government, for example, may be able to increase the value of the charn scallop aquaculture industry by focusing research efforts to specific sectors of the industry or by adjusting the current licensing system from a fixed fee system to one that accounts for economic differences in charn scallop culture success (especially if there are difference in farm size)

Conclusions

The results of the optimal bioeconomic harvesting model showed (1) the optimal harvest time for ear suspended style in both regions (i e , Chumunjin and Kojin) is longer than with the lantern net method, (2) the ear-suspended operation generated the highest expected discounted net economic returns (i e , E[NPV]) in each region, (3) the optimal month for planting spat was different for each style and region (ranging from March through July, earlier for the ear-suspended style), and (4) the market size of charn scallop that maximizes E[NPV] is between 11 42 and 13 18 cm, which is larger than traditionally marketed In addition, the relative range of optimal harvesting patterns for each scenario may indicate relative differences in risk Under the assumptions used in this study, for example, a farmer in Chumunjin using the lantern net grow-out style (Table 6-10) would forego 0 05 to 1 1 percent in returns (E[NPV]) by adopting the next best optimal rotations (i e , advancing or delaying the initial planting by one month) For comparison a farmer in Kojin using the same grow-out style (Table 6 12) would forego 1.7 to 4 4 percent in returns (E[NPV]) by advancing or delaying the initial planting by one month

Using the optimal production cycles for each style and region, the decision of when to initiate a subsequent grow-out rotation was also examined. This is necessary since with seasonality the optimal cycle may not be possible on a continual basis (i.e., if the optimal duration of grow-out is not 23 months). This was accomplished by comparing the expected net present value of the optimal rotation, discounted in successive months (to examine the returns from delaying harvest past the optimum) with the expected net present value of the rotations that would begin in those successive months (recall that returns varied by initial starting month). Once a month was found in which the returns from initiating a new rotation exceeded the decreased returns associated with delaying harvest past the optimum harvest and replacement would occur. This type of comparison was made for each culture style and region until a repeatable pattern was found. Overall repeatable patterns were found after two to four rotations. Thus long-run optimal farm-level management strategies may differ by culture type and region.

In terms of resource management issues, charn scallop licenses are currently allocated annually by the provincial government (Kangwon province in this study) in Korea under the Ministry of Maritime Affairs and Fisheries (MMAF). The licenses allow production on a 30 ha area in total (including intermediate and grow-out culture areas, equipment storage, etc.). Although the number of licenses and the license fee is fixed, the government can change the number awarded and the fee in each year. Thus, if too few licenses are awarded, license-holders stand to capture rents associated with the charn scallop resource. In general, the estimated expected net present values from this study can provide some indication of the magnitude of rents earned relative to the license fee. A comparison of this type could aid in the determination of a more tailored licensing system

or to justify expenses on future research. This may be especially useful since it appears there are differences by culture style and region.

Caveats and Future Research

The biological submodel in this study has incorporated biological and environmental data including charn scallop size-at-age water temperature, water dissolved oxygen, and water salinity. This specification excluded other potentially important environmental values including water flow and the food profile (or algal content of water) as well as biological factors such as sex (male/female growth rates). These variables would add more realism. Most notably this study could be extended to consider the optimal harvesting and rotation of charn scallops for different regions (e.g., warm water areas off the southern Kangwon province) and culture style (e.g., sowing culture). Currently, the Korean National Fisheries Research and Development Institute (KNFRDI) is examining the biological potential of charn scallop aquaculture to areas south of Kangwon. Addressing the sowing culture component of the industry may be especially important given that the hanging culture operations are dependent on the availability of wild spat (i.e., the underlying stock is an open-access resource so the potential for overfishing may exist).

Food science studies with charn scallops would also provide information on meat quality that could be used to explore differences in consumer preferences which in turn, could affect product prices. For example, if quality differences are found to vary by production method, region, or scallop size, then the price equation would need to be adjusted, which would likely affect the determination of the optimal solution and general conclusions.

Since these results were derived under specific assumptions regarding prices, demand, costs, growth, mortality rates, etc. (including *ceteris paribus* conditions), an evaluation of the results should focus on the type of information this methodology can generate rather than the specific results. Specifically, the strength in using this approach lies in the ability to systematically evaluate the economic tradeoffs associated with changing production schedules and the length of the planning horizon.

In terms of the assumptions that were made and their potential affect on the results and conclusions, a few specific examples are in order. First, the mortality rate data that was available differed by culture style but not over time (i.e., by scallop age). In one of the styles the mortality rate changed at month 10; otherwise the monthly rate was constant and identical from month 10 through 30. There is some anecdotal evidence to suggest that rates may vary by age or by stocking density, but such data was not available for this species and was not considered in this study. Second, in terms of stocking density, this study modeled a representative farm based on a typical operation as defined by Park (1998); as such, the model could not determine the optimal stocking density. Third, this study examined only two regions. Since the environmental characteristics of southern regions appear to differ (e.g., water temperatures are warmer), then this analysis could benefit by including this other region.

Fourth, although two hanging culture styles were examined, there was very little economic data associated with one of the styles (i.e., ear-suspended), especially by region. That is why direct use and comparisons of the resulting economic values generated in this study should be done with caution. Although the use of the ear-suspended style (on which there was little economic information) appeared to predict

higher economic returns, and production using this culture style has increased since the data was collected for this study (i e , 1996) no definitive conclusions should be drawn about the accuracy of the economic differences generated in this study

Fifth, in terms of economic assumptions, the model results were based on a 12 percent annual discount rate following the International Monetary Fund's guidelines. To examine the effect of alternative discount rates, the analysis was re-calculated for the lantern net style (the most prevalent style) in Chamuagun region Although the magnitude of the expected net present value of returns changed, and some differences of the relative values were found (i e , the differences between net present values were smaller) use of 7 and 5 percent annual discount rates did not change the qualitative results of the analysis

Sixth, the prediction of an optimal rotation for the average size farm does not take into account the industry effect if all farmers were to adopt the same strategy So, although the price function captured seasonal differences in demand, an aggregate market effect would likely change the results if an industry study were conducted

One final economic caveat concerns the examination of optimal long-run rotation schedules This study compared the discounted returns from delaying harvest past the optimal harvest month with the expected net present value of beginning a new rotation in successive months (i.e., a decision rule for a farmer who has already reached the optimal harvest month) Similar procedures could be used to examine alternatives associated with harvesting early Another option would be to harvest the first rotation at the optimal time and place the product in frozen inventory until optimal market time Such a scenario would require storage capacity and the payment of inventory fees. Given that the market is primarily for fresh product the market price for a previously frozen scallop would

likely be less at this time; however, such a scenario may be worth investigating if scallop production continues to increase. Lastly, an optimal multiple rotation schedule could be examined simultaneously following the optimal harvest literature for multiple rotations with forest resources; such problems typically suggest shorter initial rotations.

Again, the use of this dissertation would be most appropriately focused on the nature of the model and it's potential use for evaluating and comparing alternatives; when further economic data becomes available perhaps more definitive results can be drawn. In addition, incorporating many aspects identified in the caveats would increase and strengthen the applicability of this model.

APPENDIX

APPENDIX A
ALTERNATIVE COST FUNCTION SPECIFICATIONS AND RESULTS

An alternative set of estimations assumed that production costs for clam scallop aquaculture were linear functions of production quantity and included dummy variables for region (area) and culture style. These alternative functions are shown below:

(A.1) $TC = f(Q, DC_s, DC_a, Q \cdot DC_s, Q \cdot DC_a) =$

$$\eta_0 + \eta_1 Q + \eta_2 DC_s + \eta_3 DC_a + \eta_4 Q \cdot DC_s + \eta_5 Q \cdot DC_a$$

(A.2) $TC = f(Q, DC_s, DC_a, Q \cdot DC_s) = \eta_0 + \eta_1 Q + \eta_2 DC_s + \eta_3 DC_a + \eta_4 Q \cdot DC_s$

(A.3) $TC = f(Q, DC_s, DC_a) = \eta_0 + \eta_1 Q + \eta_2 DC_s + \eta_3 DC_a$

(A.4) $TC = f(Q, DC_a, Q \cdot DC_a) = \eta_0 + \eta_1 Q + \eta_2 DC_a + \eta_3 Q \cdot DC_a$

(A.5) $TC = f(Q, DC_a) = \eta_0 + \eta_1 Q + \eta_2 DC_a$

(A.6) $TC = f(Q, DC_s, Q \cdot DC_s) = \eta_0 + \eta_1 Q + \eta_2 DC_s + \eta_3 Q \cdot DC_s$

(A.7) $TC = f(Q, DC_s) = \eta_0 + \eta_1 Q + \eta_2 DC_s$

(A.8) $TC = f(Q) = \eta_0 + \eta_1 Q$

The parameter estimates for the linear specification based on production volume are presented in Table A-1. The R^2 value is a measure of the goodness-of-fit of the regression equation. It shows the proportion of the total variation in the dependent variable TC explained by all the explanatory variables (such as Q, DC_s, $Q \cdot DC_s$ and $Q \cdot DC_a$ in Table A-1). Generally, the fit of the model is presented to be "better" the closer is R^2 is to 1. An important property of R^2 is that it is a non-decreasing function of

the number of independent variables (i.e., explanatory variables) in the model. That is, R^2 invariably increases and never decreases with an increase in the number of regressors. Table A-1 shows the property of nondecreasing function of the number of independent variables. For example, the R^2 value of 0.856 in model (A-7) indicates that the explanatory variables explain about 85.6 percent of the variation in total costs. Although high R^2 values are desirable, they do not reflect anything about the significance of the individual explanatory variables.

Model (A-1) hypothesizes there is a relationship between total costs and total production, culture style, and culture area and that the extent of that relationship varies by production-culture style and production-culture area interactions. The t-statistics in the case of model (A-7), indicate high significance levels overall, sufficiently high that estimates of almost all coefficients are statistically significant. The partial regression coefficient of 0.0046 on production volume in model (A-7) means that, holding all other variables constant, as charm scallop production increases, say by one kg, the mean total cost increases by 0.46 million won. Also, model (A-7) contains one quantitative variable (production volume) and one qualitative variable (culture style to reflect production by lantern net or ear-suspended technology). The model postulates that total costs differ by production style in only the amount of fixed costs (since they have the same slope (η_1) on production but different intercepts). In other words, it is assumed that the level of the lantern net mean total cost is different from that of the ear suspended men total cost (η) but the rate of change in the mean total cost by production is the same for both culture style. Models (A-4) and (A-5) also show that area affects total production costs.

Table A-1 Total Cost Function Regression Results (Linear Functions by Production)

Variable	Models							
	A 1	A-2	A 3	A-4	A 5	A-6	A-7	A 8
Intercept	39 51	75.23	152.15**	-22.05	52 66	63 13	177.22*	21 16
	(265.25)	(255.31)	(83 93)	(41 94)	(33.49)	(248 71)	(83.23)	(31 14)
Q	0 0035	0 0028	0.0045*	0.0048*	0.0037*	0.0027	0 0046*	0 0038*
	(0 0022)	(0 0019)	(0 0004)	(0 0005)	(0 0004)	(0 0019)	(0 0004)	(0.0004)
DC_1	-61.57	85.24	149.23*			82.19	103 43*	
	(260.83)	(255.07)	(57 07)			(250.34)	(47.43)	
DC_4	23 62	-12.10	15 84	61 90	59 62**			
	(63 58)	(32 17)	(31 96)	(55 44)	(20 97)			
$Q \cdot DC_1$	0 0013	0.0019				0 0019		
	(0 0022)	(0 0020)				(0 0019)		
$Q \cdot DC_4$	-0 0007			-0 0017*				
	(0.0011)			(0 0007)				
R	0 865	0 863	0.857	0.856	0 817	0 862	0 858	0 788
Ad R	0.835	0.860	0.839	0 856	0 802	0 844	0 845	0 779
F	28 25	36.11	48 08	47.67	55 68	49 88	75.32	96 43
RSS	115397	117642	122193	123057	157001	118365	123398	161852

Standard errors are in parentheses A single asterisk indicates significance at a 5% level Double asterisk represents significance at a 10% level

Table A-2 summarizes the results of F-tests conducted between all possible combinations of models A-1 through A-8 Details of this test are available in the main text Since not all models can be compared (only the nested and non nested (restricted and unrestricted) models can, the selection of the "best" model may need to rely on some assumptions regarding transitivity Since these models were not used in the bioeconomic analysis, no conclusions regarding the best model were made

Table A-2 Testing Linear Restrictions (Linear Functions by Production)

Model	F-table value (F)	Computed F value (F^*)	Best Model
(A-1) versus (A-2)	F(1,22) = 5.301	0.428	Equation (A-2)
(A-1) versus (A-3)	F(2,22) = 3.443	0.648	Equation (A-3)
(A-1) versus (A-4)	F(2,22) = 3.443	0.730	Equation (A-4)
(A-1) versus (A-5)	F(3,22) = 3.049	2.644	Equation (A-5)
(A-1) versus (A-6)	F(2,22) = 3.443	0.283	Equation (A-6)
(A-1) versus (A-7)	F(3,22) = 3.049	0.502	Equation (A-7)
(A-1) versus (A-8)	F(4,22) = 2.817	3.167	Equation (A-1)
(A-2) versus (A-3)	F(1,23) = 5.279	1.059	Equation (A-3)
(A-2) versus (A-5)	F(2,23) = 3.422	3.847	Equation (A-2)
(A-2) versus (A-6)	F(1,23) = 5.279	0.142	Equation (A-6)
(A-2) versus (A-7)	F(2,23) = 3.422	0.552	Equation (A-7)
(A-2) versus (A-8)	F(3,23) = 3.028	5.185	Equation (A-2)
(A-3) versus (A-5)	F(1,24) = 5.260	6.837	Equation (A-3)
(A-3) versus (A-7)	F(1,24) = 5.260	0.215	Equation (A-7)
(A-3) versus (A-8)	F(2,24) = 3.403	5.859	Equation (A-3)
(A-4) versus (A-5)	F(1,24) = 5.260	6.620	Equation (A-4)
(A-4) versus (A-8)	F(2,24) = 3.403	5.733	Equation (A-4)
(A-5) versus (A-8)	F(1,25) = 5.242	3.957	Equation (A-8)
(A-6) versus (A-7)	F(1,24) = 5.260	0.998	Equation (A-7)
(A-6) versus (A-8)	F(2,24) = 3.403	6.436	Equation (A-6)
(A-7) versus (A-8)	F(1,25) = 5.242	11.875	Equation (A-7)

The same specifications are used to estimate cost as a function of area cultured as measured by hectares).

(A 9) $TC = f(ha, DC_s, DC_a, ha\ DC_s, ha\ DC_a) =$

$$\eta_0 + \eta_1 ha + \eta_2 DC_s + \eta_3 DC_a + \eta_4 ha\ DC_s + \eta_5 ha\ DC_a$$

(A 10) $TC = f(ha, DC_s, DC_a, ha\ DC_s) = \eta_0 + \eta_1 ha + \eta_2 DC_s + \eta_3 DC_a + \eta_4 ha\ DC_s$

(A 11) $TC = f(ha\ DC_s, DC_a) = \eta_0 + \eta_1 ha + \eta_2 DC_s + \eta_3 DC_a$

(A 12) $TC = f(ha, DC_a, ha\ DC_a) = \eta_0 + \eta_1 ha + \eta_2 DC_a + \eta_3 ha\ DC_a$

(A 13) $TC = f(ha\ DC_a) = \eta_0 + \eta_1 ha + \eta_2 DC_a$

(A.14) $TC = f(ha\ DC_s, ha\ DC_s) = \eta_0 + \eta_1 ha + \eta_2 DC_s + \eta_3 ha\ DC_s$

(A.15) $TC = f(ha\ DC_s) = \eta_0 + \eta_1 ha + \eta_2 DC_s$

(A.16) $TC = f(ha) = \eta_0 + \eta_1 ha$

Empirical results of models (A-9 through A-16) are shown in Table A 3 The corresponding F tests are shown in Table A-4

To examine non-linear cost functions by farm size the following functions (which are identical to models C1 through C8 that were estimated in the main text based on production volume) were also estimated

(A 17) $TC = f(ha, ha^2, ha^3, DC_s, DC_a\ ha\ DC_s, ha\ QDC_a) =$

$$\eta_0 + \eta_1 ha + \eta_2 ha^2 + \eta_3 ha^3 + \eta_4 DC_s + \eta_5 DC_a + \eta_6 ha\ DC_s + \eta_7 ha\ DC_a$$

(A 18 $TC = f(ha, ha, ha^3, DC_s\ DC_a, ha\ DC_s) =$

$$\eta_0 + \eta_1 ha + \eta_2 ha^2 + \eta_3 ha^3 + \eta_4 DC_s + \eta_5 DC_a + \eta_6 ha\ DC_s$$

Table A-3 Total Cost Function Regression Results by Hectare (Linear Functions)

	Models							
Variable	A-9	A 10	A 11	A 12	A 13	A 14	A 15	A 16
Intercept	153.82	1.81	105.20	38.90	13.05	-187.89	16.80	25.14
	(302.59)	(335.02)	(75.34)	(49.14)	(38.31)	(385.95)	(73.21)	(39.80)
ha	48.104*	33.15	36.52*	32.91*	28.15*	33.15	27.62*	27.76*
	(19.17)	(20.61)	(3.04)	(5.88)	(2.88)	(23.94)	(3.51)	(3.21)
DC_1	115.92	35.29	73.39	15.48		83.98	5.84	
	(299.21)	(335.62)	(51.66)	(69.21)		(388.26)	(55.46)	
DC_a	46.723	105.29*	185.688*		-85.99*			
	(65.85)	(35.37)	(33.71)		(31.22)			
ha DC_1	-45.19	-6.79				5.66		
	(18.81)	(28.84)				(25.21)		
ha DC_a	15.95*			9.01				
	(5.63)			(5.35)				
R^2	0.862	0.818	0.817	0.821	0.801	0.743	0.743	0.742
Adj R	0.831	0.786	0.794	0.795	0.785	0.711	0.722	0.732
F	27.46	23.77	35.85	36.63	50.41	23.14	36.05	75.93
RSS	118283	156239	156960	153504	170161	220002	220503	220604

Standard errors are in parentheses. A single asterisk indicates significance at a 5% level. Double asterisk represents significance at a 10% level.

(A.19) $TC = f(ha, ha^2, ha^3, DC_1, DC_a) = \eta_0 + \eta_1 ha + \eta_2 ha^2 + \eta_3 ha^3 + \eta_4 DC_1 + \eta_5 DC_a$

(A.20) $TC = f(ha, ha^2, ha^3, DC_a, ha\ DC_a) =$

$$\eta_0 + \eta_1 ha + \eta_2 ha^2 + \eta_3 ha^3 + \eta_4 DC_a + \eta_5 ha\ DC_a$$

(A.21) $TC = f(ha, ha^2, ha^3, DC_a) = \eta_0 + \eta_1 ha + \eta_2 ha^2 + \eta_3 ha^3 + \eta_4 DC_a$

Table A-4. Testing Linear Restrictions (Hectare)

Model	F-table value (F)	Computed F value (F*)	Best Model
(A-9) versus (A-10)	F(1,22) = 5.301	7.064	Equation (A-9)
(A-9) versus (A-11)	F(2,22) = 3.443	3.599	Equation (A-9)
(A-9) versus (A-12)	F(2,22) = 3.443	3.278	Equation (A-12)
(A-9) versus (A-13)	F(3,22) = 3.049	3.218	Equation (A-9)
(A-9) versus (A-14)	F(2,22) = 3.443	9.463	Equation (A-9)
(A-9) versus (A-15)	F(3,22) = 3.049	6.340	Equation (A-9)
(A-9) versus (A-16)	F(4,22) = 2.817	5.760	Equation (A-9)
(A-10) versus (A-11)	F(1,23) = 5.279	0.106	Equation (A-11)
(A-10) versus (A-13)	F(2,23) = 3.422	1.025	Equation (A-13)
(A-10) versus (A-14)	F(1,23) = 5.279	9.387	Equation (A-10)
(A-10) versus (A-15)	F(2,23) = 3.422	5.730	Equation (A-10)
(A-10) versus (A-16)	F(3,23) = 3.028	3.158	Equation (A-10)
(A-11) versus (A-13)	F(1,24) = 5.260	2.019	Equation (A-13)
(A-11) versus (A-15)	F(1,24) = 5.260	9.716	Equation (A-11)
(A-11) versus (A-16)	F(2,24) = 3.403	5.866	Equation (A-11)
(A-12) versus (A-13)	F(1,24) = 5.260	2.604	Equation (A-13)
(A-12) versus (A-16)	F(2,24) = 3.403	5.245	Equation (A-12)
(A-13) versus (A-16)	F(1,25) = 5.242	7.411	Equation (A-13)
(A-14) versus (A-15)	F(1,24) = 5.260	0.055	Equation (A-15)
(A-15) versus (A-16)	F(2,24) = 3.403	0.033	Equation (A-16)
(A-15) versus (A-16)	F(1,25) = 5.242	0.012	Equation (A-16)

(A.22) $TC = f(ha, ha^2, ha^3, DC_s, ha \cdot DC_s) =$

$$\eta_0 + \eta_1 ha + \eta_2 ha^2 + \eta_3 ha^3 + \eta_4 DC_s + \eta_5 ha \cdot DC_s$$

(A.23) $TC = f(ha, ha^2, ha^3, DC_s) = \eta_0 + \eta_1 ha + \eta_2 ha^2 + \eta_3 ha^3 + \eta_4 DC$

(A.24) $TC = f(ha, ha^2, ha^3) = \eta_0 + \eta_1 ha + \eta_2 ha^2 + \eta_3 ha^3$

Table A-5 shows the parameter estimates related to cubic functions by hectare and the corresponding F test results are summarized in Table A-6. The t-statistics in the case of model (A.19) indicate high significance levels overall, sufficiently high that estimates of almost all coefficients are statistically significant. Also we see that total cost depends on both culture style and culture location (area) through model (A.19).

The R^2 in model (A.19) indicates that the explanatory variables explained 92.5 percent of the variation in total costs. The adjusted R^2 in model (A.19) shows that, after taking into account the degrees of freedom, the explanatory power falls to 90.8 percent.

Graphing the results of selected empirical models to show the relationship between total cost-production and total cost-hectare. The empirical cost functions used to drive the total cost curves are shown in the figures that follow.

Figure A.1 shows

(A.4) $TC = f(Q) = -22.05 + 0.0048Q$

(A.4) $TC = f(Q, DC_o, Q \cdot DC_o) = -22.05 + 0.0048Q + 61.90DC_o - 0.0017Q \cdot DC_o$

(A.7) $TC = f(Q) = -177.22 + 0.0046Q$

(A.7) $TC = f(Q, DC_s) = -177.22 + 0.0046Q + 163.43DC_s$

Figure A.2 shows

(A.9) $TC = f(ha) = -153.82 + 48.1ha$

Table A-5 Total Cost Function Regression Results (Cubic Functions by Hectare)

Variable	Models 1	2	3	4	5	6	7	8
Intercept	209.22	-180.84	0.58	135.46	-134.70	-413.02	-186.93**	-238.92*
	(265.44)	(262.52)	(97.62)	(117.56)	(115.06)	(325.41)	(107.89)	(112.02)
ha	109.75*	112.66*	97.79*	87.31*	85.64*	145.06*	125.68*	109.67*
	(32.75)	(32.46)	(25.35)	(33.67)	(34.78)	(39.89)	(30.90)	(31.93)
ha^2	7.36*	8.10*	7.75*	-6.34*	-6.11*	-10.37*	-9.95*	-8.10*
	(2.36)	(2.21)	(2.14)	(2.07)	(2.64)	(2.70)	(2.62)	(2.64)
ha^3	0.212	0.23*	0.23*	0.18*	0.18*	0.29*	0.28*	0.23*
	(0.06)	(0.06)	(0.05)	(0.08)	(0.07)	(0.07)	(0.07)	(0.06)
DC_r	52.40	28.02	-139.68*			120.30	90.28*	
	(230.38)	(227.87)	(36.39)			(287.86)	(43.33)	
DC_s	-46.86	-90.15*	-91.05*	70.93	-59.66*			
	(53.18)	(23.67)	(23.40)	(66.53)	(27.71)			
ha DC_s	12.72	-10.61				-13.34		
	(15.46)	(15.21)				(18.03)		
ha DC_s	-5.39			1.10				
	(5.83)			(5.86)				
R	0.910	0.927	0.925	0.875	0.875	0.877	0.874	0.850
Adj R	0.906	0.906	0.908	0.847	0.854	0.849	0.852	0.831
F	38.02	45.59	55.50	30.93	40.34	31.35	48.53	45.37
RSS	59848	62326	63976	106657	106826	105388	108010	128366

Standard errors are in parentheses. A single asterisk indicates significance at a 5% level. Double asterisk represents significance at a 10% level.

Table A-6. Testing Linear Restrictions (Cubic Functions by Hectare)

Model	F-table value (F)	Computed F value (F*)	Best Model
(A-17) versus (A-18)	F(1,20) = 5.351	0.828	Equation (A-18)
(A-17) versus (A-19)	F(2,20) = 3.493	0.690	Equation (A-19)
(A-17) versus (A-20)	F(2,20) = 3.493	7.821	Equation (A-17)
(A-17) versus (A-21)	F(3,20) = 3.098	5.233	Equation (A-17)
(A-17) versus (A-22)	F(2,20) = 3.493	7.609	Equation (A-17)
(A-17) versus (A-23)	F(3,20) = 3.098	5.365	Equation (A-17)
(A-17) versus (A-24)	F(4,20) = 2.866	5.724	Equation (A-17)
(A-18) versus (A-19)	F(1,21) = 5.325	0.556	Equation (A-19)
(A-18) versus (A-21)	F(2,21) = 3.467	7.497	Equation (A-18)
(A-18) versus (A-22)	F(1,21) = 5.325	15.510	Equation (A-18)
(A-18) versus (A-23)	F(2,21) = 3.467	7.697	Equation (A-18)
(A-18) versus (A-24)	F(3,21) = 3.072	7.417	Equation (A-18)
(A-19) versus (A-21)	F(1,22) = 5.301	15.736	Equation (A-19)
(A-19) versus (A-23)	F(1,22) = 5.301	15.143	Equation (A-19)
(A-19) versus (A-24)	F(2,22) = 3.443	11.071	Equation (A-19)
(A-20) versus (A-21)	F(1,22) = 5.301	0.035	Equation (A-21)
(A-20) versus (A-24)	F(2,22) = 3.443	2.239	Equation (A-24)
(A-21) versus (A-24)	F(1,23) = 5.279	5.637	Equation (A-21)
(A-22) versus (A-23)	F(1,22) = 5.301	0.547	Equation (A-23)
(A-22) versus (A-24)	F(2,22) = 3.443	2.398	Equation (A-24)
(A-23) versus (A-24)	F(1,23) = 5.279	5.335	Equation (A-23)

(A.9) $TC = f(ha, DC_a, ha \cdot DC_a) = -153.82 + 48.1ha + 46.723DC_a - 14.95ha \cdot DC_a$

(A.13) $TC = f(ha) = 13.05 + 28.15ha$

(A.13) $TC = f(ha, DC_a) = 13.05 + 28.15ha - 84.99DC_a$

Figure A.3 shows:

(A.19) $TC = f(ha, ha^2, ha^3, DC_s, DC_a) =$

$0.58 + 97.79ha - 7.75ha^2 + 0.23ha^3 - 139.68DC_s - 91.05DC_a$

(A.19) $TC = f(ha, ha^2, ha^3, DC_a) = -134.7 + 85.64ha - 6.11ha^2 + 0.18ha^3 - 59.66DC_a$

(A.21) $TC = f(ha, ha^2, ha^3) = 0.58 + 97.79ha - 7.75ha^2 + 0.23ha^3$

(A.21) $TC = f(ha, ha^2, ha^3) = -134.7 + 85.64ha - 6.11ha^2 + 0.18ha^3$

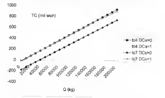

Figure A-1: Total Cost Function Based on Table A-1

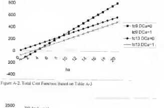

Figure A-2. Total Cost Function Based on Table A-3

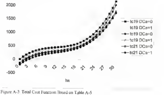

Figure A-3 Total Cost Function Based on Table A-5

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BIOGRAPHICAL SKETCH

Jong du Choi was born in Kangwon, Korea, December 12, 1967. He is the oldest son of Hyangkyun Park and Seokyo Choi and has one younger brother. He started his college education at the Kangwon National University in Korea in 1986 where he received a Bachelor of Business Administration in 1993. When he was an undergraduate, he received full scholarships from the university and Samyang (a private company) in Korea during his undergraduate years. He became involved in the Korea Youth Association at Kangwon National University, holding the office of president. He also worked for the Korean army from April 1988 to June 1990. He received a Master of Business Administration from Kangwon National University in 1995. During his graduate studies at Kangwon National University he was the president of the Graduate Assistant Association. In May 1995, he began working at the Korea Rural Economic Institute as a researcher in the Forestry and Fishery Economic Division. He also worked for the Fishery Policy Division in the Korea Maritime Institute in 1997. He entered the graduate program in the Food and Resource Economics Department at the University of Florida in August 1997. While attending classes, he worked as a research assistant and served as president of the Korea Student Association at the University of Florida for two years. He plans to go back to Korea to accept an associate researcher position in the Korea Maritime Institute after graduation in December 2002.

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December 2002

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